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Review of salient trends and issues on energy development and use in the context of sustainable development: energy and the residential sector

Energy and the residential sector

Report of the Secretary-General

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Introduction

1. The present report has been prepared in response to the request of the Committee on Energy and Natural Resources for Development at its first session (5-16 April 1999),[1] which was approved by the Economic and Social Council at its substantive session of 1999 (Council decision 1999/277).

2. World energy demand in the residential sector is projected to increase substantially, by more than a 2 per cent average annual rate of growth in the next decade with the total residential energy consumption having risen to over 2,200 mtoe (millions of tons of oil equivalent) by 2010 owing to increases in population, urbanization and per capita incomes. An increased penetration of energy-intensive appliances in households that have not yet reached saturation, mainly in developing countries and countries in transition, is expected as part of this trend. In Organisation for Economic Cooperation and Development (OECD) countries, electricity will be gaining in share during the period extending to 2010, rising to about 43 per cent of the total residential energy demand of over 1,200 mtoe. Energy used in the residential sector accounts for about one quarter of total energy consumed in industrialized countries, ranging from 20 per cent in France to 29 per cent in Sweden. In the rest of the world, the average annual growth rate of residential energy demand is estimated to be about 6 per cent and the total residential energy demand rising to over 1,000 mtoe, with a significant rise in the share of electricity. As a percentage of total energy consumed, residential energy varies widely among developing countries. For example, this figure was approximately 14 per cent in Egypt and China, but as high as 31 per cent in Zimbabwe and 36 per cent in India.

3. There are four principal uses of energy in this sector, namely, climate control (heating, of both space and water, and cooling of space), cooking, lighting and powering appliances. Generally, residential energy demand is affected by socio-economic development, culture and mores as well as climatic conditions. The environmental impact of increases in energy use in this sector depends largely on the type of fuel used and how it is produced. While policies undertaken to curb residential energy demand have the potential to reduce total energy used, those undertaken to promote more efficient technologies can have a significant impact on greenhouse gas emissions and pollution abatement at any given level of demand.

4. Following significant oil price increases in the 1970s, energy policies in many industrialized countries were aimed at reducing residential energy demand. Tax incentives were provided to encourage energy-saving devices in homes and buildings, and standards were applied to energy-consuming goods. Since the mid-1980s, energy price declines in real terms have relaxed the urgency of this issue for policy makers as well as for individual consumers. However, more recently, concerns about the environment and individual health have provided the impetus to refocus attention on residential sector energy use.

5. Information on residential energy use is incomplete and/or lacking in many countries. Though recent efforts at improving the gathering and compilation of disaggregated data have yielded positive results, especially in Eastern European countries, many countries still lack sufficient data to analyse residential energy use patterns. In addition, data problems exist for non-traded energy which comprises a significant portion of energy used by households in developing countries.

I. Residential energy consumption

6. The residential sector consists of a large number of consumers using similar equipment for similar purposes and, in the past, was considered, by and large, homogeneous. However, significant differences occur across socio-economic groups, regions and countries depending on income levels and use of leisure time, cultural differences and climate, all of which have an impact on final energy demanded by households. Structural and technological factors, as well as climatic factors, also affect energy demand in the household sector. Furthermore, taxes and other policy measures have an impact on final energy use in this sector. Table 1 categorizes factors affecting energy consumption with respect to consumption over time and across countries and cultures.

Table 1
Factors affecting residential energy consumption

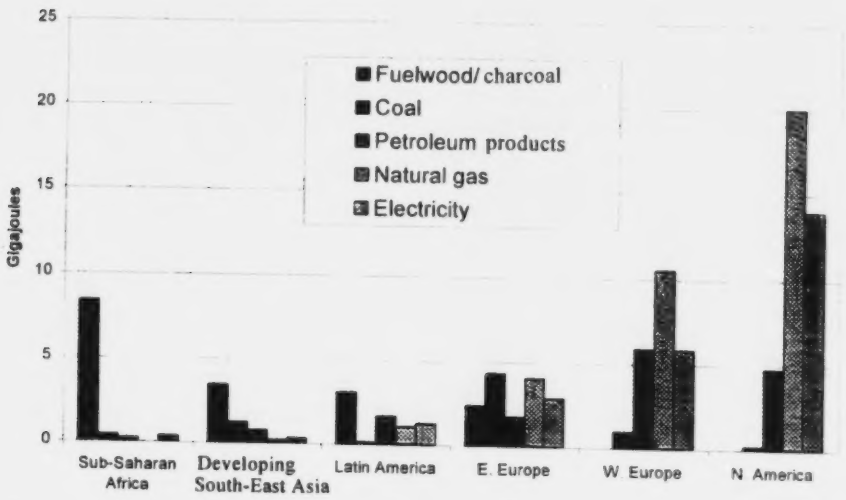
Demographics	Household growth or decline Population growth Age of occupants
Economic factors	Energy prices Investment costs of equipment Available income
Individual factors	Attitude Awareness
Lifestyle	Time spent at work/home Mix of activities Rural/urban
Culture	Cooking/washing/heating/comfort Traditions
Structure	Saturation of equipment Dwelling area Share of central heating
Technology	Efficiency
Climate	Differences in heating degree days Building and appliance standards
Policy	Taxes, subsidies Effects of demand-side management programmes

Source: Based on R. Haas, "Energy efficiency in the residential sector", *Energy Policy*, vol. 25, Nos. 7-9, pp. 789-802.

7. In a comprehensive analysis of this sector at the national level, energy use is typically broken down and analysed by end-use components such as space heating, water heating, cooking, lighting and electric appliances. However, such analyses are often complicated by lack of adequate data about these components and/or competing trends hidden in the available aggregated data. For example, in industrialized countries, the amount of energy required to heat one square metre (m^2) of floor space fell by 20-50 per cent between 1973 and 1993,[2] yet the trend towards larger, separated housing units and smaller household sizes may have

outweighed this efficiency gain. Detailed data for a disaggregated analysis of residential energy use are unavailable in many countries.

Figure I
Residential energy consumption by fuel type and region, 1994



Source: O. Dzioubinski and R. Chipman, "trends in consumption and production: household energy consumption, Department of Economic and Social Affairs of the United Nations Secretariat Discussion Paper No. 6 New York, April 1999.

8. Concerns about growing energy demand in the residential sector have led to demand-side management policy measures undertaken in some, mostly industrialized, countries to provide energy efficiency information to users of appliances as an input in their purchase decisions. In 1987, the United States of America adopted national standards for refrigerators and freezers, boilers, air conditioning appliances and other appliances and, by 1992, such standards included fluorescent and incandescent lamps and electric motors. Consequently, a standard size refrigerator/freezer, which consumed an average of 2,000 kilowatt hours (kWh) per year in 1970, used 900 kWh per year in 1990 and 690 kWh per year in 1993.[3] However, efficiency improvements in other countries may be less dramatic depending on initial energy efficiency levels and the incidence of compliance by manufacturers. One barrier to improved residential efficiency has been that appliance energy costs are a small sum in household budgets, resulting in lack of incentive by consumers to investigate the often complicated question of energy efficiency.

9. Energy efficiency labelling has been introduced in such countries as Australia, Canada, Denmark and France, among others, and various voluntary plans exist, mostly in industrialized countries. Energy standards and/or labelling schemes, often as part of demand-side management programmes, are now under consideration and application in some developing countries as well. Such programmes may prove

effective as household incomes, and associated purchases of household appliances, increase with expected economic growth. Table 2 summarizes the status of labelling and standards programmes in selected industrialized and developing countries.

Table 2
Energy efficiency labels and standards in selected countries

	United States (1978)	*Japan (1979)*	*India (1979)*	*Australia (1986)*	*China (1989)*	*Democratic People's Republic of Korea (1992)*	*Philippines (1993)*	*Thailand (1994)*	*Switzerland (1994)*	*Mexico (1995)*	*Hong Kong, China (1995)*	*Canada (1995)*	*European Union (EU) (1995)*	*Singapore*	*New Zealand*	*Russian Federation*	*Republic of Korea*
Refrigerators	L_m, S_m	L_v, S_v	S_v	L_m	S_m	L_m, S_m		L_v	S	L, S		L, S	L				
Freezers	L_m, S_m	L_v, S_v		L_m					S			L, S	L				
Space heaters	S_m			L_m		L_m											
Ranges/ovens	S_m								S			S					
Room AC	L_m, L_v, S_m	L_v, S_v	S_v	L_m	S_m	L_m, S_m	L_m, S_m	L_v		L_m, S_m	L_v	L_m, S_m		S_m	L_v	S_m	L_m, S_m, S_v
Central AC	L_m, S_m	S_v	S_v		S_m	L_m, S_m						S					
Water heaters	L_m, S_m			L_m		L_m						S					
Heat pumps	S_m	S_v										S					
Dishwashers	L_m, S_m			L_m					S			L, S					
Clothes washers	L_m, S_m			L_m	S_m				S			L, S					
Clothes dryers	S_m			L_m					S			L, S					
Televisions		S_v			S_m				S								
VCRs		S_v							S								
Lamps	L_m	S_v				L_m											
Ballasts	L_m					L_m											
Furnaces	L_m, S_m								S			S					
Fans					S_m												
Rice cookers					S_m												
Electric kettles																S_m	
Irons					S_m											S_m	
Vacuum cleaners																S_m	
Shower heads	L_m, S_m																
Faucets	L_m, S_m																
Motors						L_m		L_v									

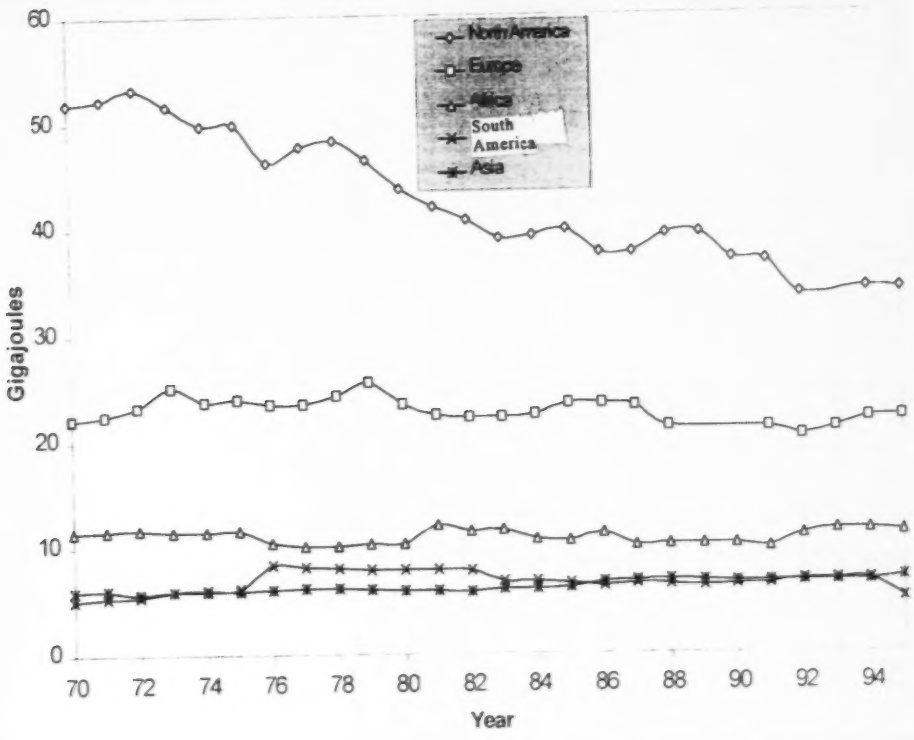
	United States (1978)	*Japan (1979)*	*India (1979)*	*Australia (1986)*	*China (1989)*	*Democratic People's Republic of Korea (1992)*	*Philippines (1993)*	*Thailand (1994)*	*Switzerland (1994)*	*Mexico (1995)*	*Hong Kong, China (1995)*	*Canada (1995)*	*European Union (EU) (1995)*	*Singapore*	*New Zealand*	*Russian Federation*	*Republic of Korea*
Boilers						L_m											
Computers	L_v	S_v															
Hard-disk drives		S_v															
Copiers	L_v	S_v															
Fax	L_v																
Printers	L_v																
Monitors	L_v																
Range hoods	L_v																
Transformers	L_v																
Radio receivers					S_m												

Source: Stephen Wiel, "The importance of energy efficiency labels and standards for appliances, equipment and lighting products", Lawrence Berkeley National Laboratory, presented at Energex 2000.

Note: Year in parentheses indicates year in which labels or standards were first established.

Symbols: L = labels; S = standards; L_v = voluntary labels; L_m = mandatory labels; S_v = voluntary standards; S_m = mandatory standards.

Figure II
Per capita household energy consumption in various regions, 1970-1995



Source: O. Dzioubinski and R. Chipman, "Trends in consumption and production: household energy consumption, Department of Economic and Social Affairs of the United Nations Secretariat Discussion Paper No. 6, New York, April 1999.

10. Another demand-side policy undertaken in some countries has been the encouragement of the use of compact fluorescent lamps (CFLs) in the household sector, and programmes in developing countries have received multilateral funding. Energy conserved by CFL use is considerable at up to 80 per cent of energy used in conventional lighting. Incentives have been provided in a number of countries including Brazil, Denmark, Jamaica, Lithuania, Mexico, Poland, Peru, Thailand, and the United Kingdom of Great Britain and Northern Ireland. Incentives provided have ranged from free CFLs to subsidies and rebates. The Global Environment Facility (GEF) has financed a number of CFL projects in developing countries. Moreover, global markets have expanded with developing countries' participation growing. Expiring patents are expected to result in lower prices which may make CFLs more attractive in industrialized and developing countries.

II. Regional perspectives

11. Although residential energy patterns differ across countries as the factors noted above vary, certain regional trends can be distinguished and may be useful in determining appropriate policy measures for an efficient allocation of resources in this sector. Figure I shows residential energy consumption by fuel type and illustrates the differences across regions. Most industrialized countries have reached a saturation point with regard to appliance use and consumption and are generally not responsive to energy price changes for residential energy services. Regulation and demand-side management policies may be more appropriate as policy measures in these countries than taxes and subsidies. While population growth has tapered off in many industrialized countries, the trend towards larger home sizes and smaller households points to increases in per capita energy use in this sector, though continued improvements in efficiency may continue to offset these trends.

12. Developing countries, on the other hand, are expected to record increases in per capita residential energy use as incomes increase with globalization and economic growth, and urbanization trends continue. Also, as developing countries solve the problem of energy access in rural areas, use of electricity will increase dramatically. Efficiency standards for new appliances, building codes and the elimination of energy subsidies may be appropriate policies in many developing countries, in addition to encouraging environmental standards on electricity generation facilities.

A. OECD countries

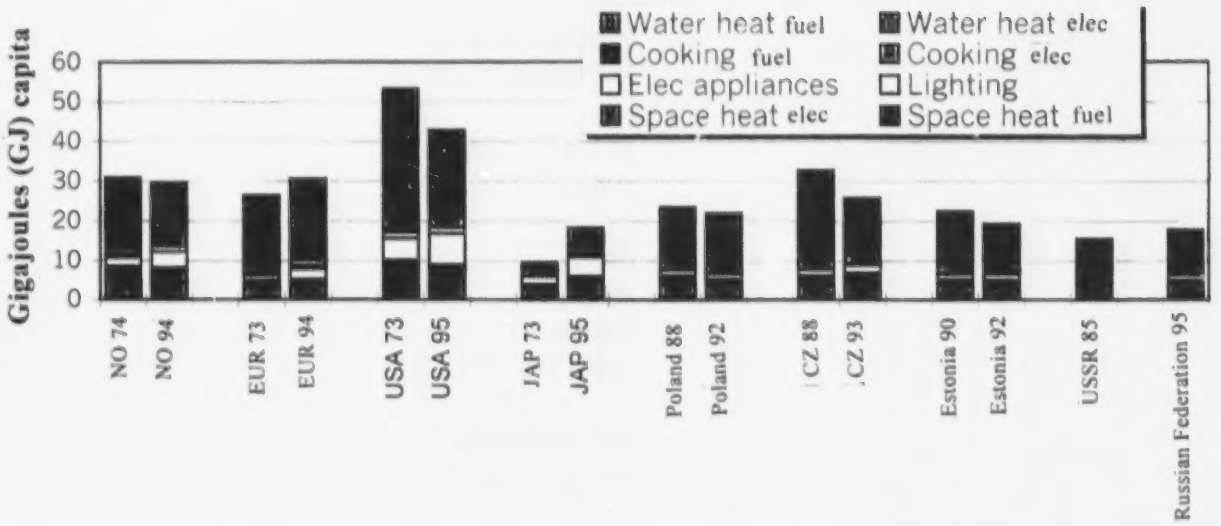
13. North American and European countries, accounting for 18 per cent of the 1997 world population, have the highest per capita household energy consumption levels, as shown in figure II. Per capita household energy consumption provides an indicator reflecting differences in lifestyles as well as income levels and prices in industrialized countries. Since the early 1970s, North America has experienced a decline in per capita household energy consumption although that consumption remains the highest in the world on a per capita basis as well as in absolute terms.

14. Recent household surveys in the United States reveal interesting changes in household energy indicators during the 19-year period between 1978 and 1997.[4] The number of households located in the southern United States increased by 44 per cent, from 25 million in 1978 to 36 million in 1997. The number of households also increased significantly in the western United States, by 57 per cent, from 8 million to 14 million. In the north-east and Mid-West regions, with colder climates, the number of households increased more modestly, by 18 per cent and 14 per cent, respectively. These changes would have a negative impact on heating fuel use, but electricity would be more likely to be used in warmer climates in the southern and parts of the western United States. Accordingly, there were significant changes in type of fuel used for heating during this period. As a proportion of total households, those using natural gas and fuel oil or kerosene declined by 3 per cent and 12 per cent, respectively, while those using electricity rose by 14 per cent over the 19-year period.[5] Given the significance of heating as an energy service in the United States and the long-term nature of the heating fuel decision, this is a significant development. Also, appliance use increased substantially during this period. Figure III shows residential fuel use in the United States having declined from 1973 to

1995, but having still remained significantly higher than that of other countries with similar income levels. Space heating fuel declines accounted for the bulk of this decrease.

Figure III

Per capita residential energy consumption by fuel type, selected countries



Source: IEA, *Energy Efficiency*, vol. 1 (Paris, OECD, 1998), chap. 3.

Note: NO = Denmark, Finland, Norway, Sweden; EUR = Italy, France, United Kingdom, and the western part of Germany; CZ = Czech Republic; JAP = Japan.

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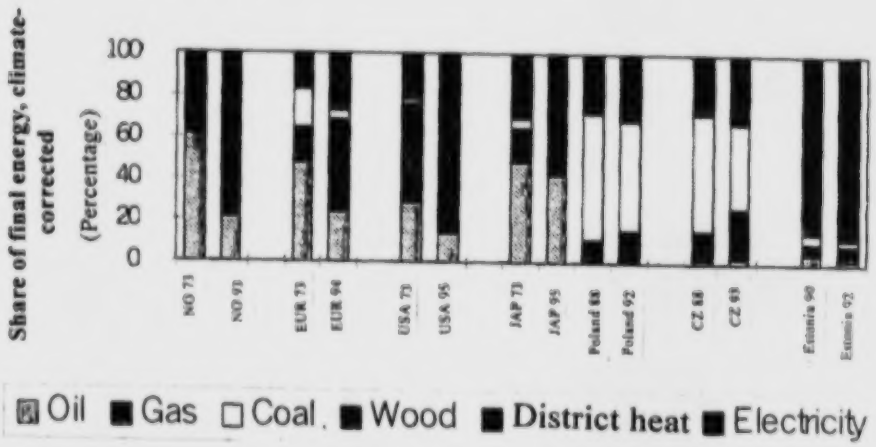
15. Per capita consumption of energy in the residential sector by European countries has remained relatively constant, as indicated in figure II, though differences among countries exist, especially between OECD countries located in Europe and non-OECD European countries, as shown in figures I and III. In OECD-Europe, energy efficiency in household appliances has improved significantly in recent years and the saturation level of household appliances is thought to be close to maximum. One recent study of consumption of household appliances in Austria showed that, though appliance electricity consumption in 1995 had been seven times higher than in 1960 and that service demand for appliances grew considerably, increases in efficiency of appliances partially counteracted these trends.[6] Income was found to be the most significant determinant of demand for household appliances, and consumers were responsive to changes in income when purchasing appliances. On the other hand, the effects of changes in electricity prices on the demand for appliances were found to be negligible. These findings point to the effectiveness of appliance standards rather than energy taxes as a means of promoting energy efficiency or a more rational use of energy for appliances in households.

Figure IV
Residential sector fuel shares in selected countries



Source: IEA, *Energy Efficiency*, vol. 1 (Paris, OECD, 1998), chap. 3.
Note: NO = Denmark, Finland, Norway, Sweden; EUR = Italy, France, United Kingdom, the western part of Germany; CZ = Czech Republic; JAP = Japan.

16. There has been some support for these findings in studies of other OECD countries. In Japan, for example, an examination of factors affecting the purchase of air conditioners (ACs) found that consumers were much more responsive to changes in the appliance price than to changes in electricity prices.[7] In a study of residential energy in Norway, it was found that income and price elasticity were both less than one (indicating that consumers were not very responsive to changes in income and prices) but that higher-income consumers were more responsive to changes in

energy prices than lower-income consumers.[8] This may reflect a change in luxury appliance use when energy prices change. Findings in Great Britain support these results.[9] A more inclusive examination of OECD countries showed that income elasticity had declined as appliance and heating saturation was approached.[10] In OECD countries, it is expected that energy consumption will not necessarily continue to rise as much as incomes increase since most households have already made major appliance purchases, especially for space and water heating and cooking.

17. These results tend to indicate that prices (or taxes on energy products and/or electricity) as a policy tool to affect residential energy demand in industrialized countries will have limited impact. As households in industrialized countries reach saturation with regard to appliances and heating and/or cooling units, turnover of appliances rather than purchase of additional appliances becomes the norm. Applying and/or regulating technical standards may be a more effective policy tool for influencing energy use in the household sector.

18. Generally, residential energy consumption in industrialized countries will depend on the continued trend towards individual detached housing units, increased efficiency of heating systems, changes in lifestyle and habits, efficiency in the provision of lighting services (such as the use of compact flourescent lamps), trends in efficiency and use of household appliances, and space and water heating needs.

B. Non-OECD European countries

19. Non-OECD European countries comprise Eastern Europe and the former Soviet Union and account for approximately 7 per cent of the world population. Their geographical location necessitates that a significant portion of household energy be used for space and water heating. Residential building size per family is typically smaller than that found in the OECD countries, with overall residential space one half to one third of that in OECD-European countries. However, heating systems and appliances may not be as efficient as those in industrialized countries with regard to energy use. District heating systems in non-OECD countries are, in many cases, outdated and inefficient.

20. Figure I shows per capita household energy consumption by energy type and indicates that, in Eastern Europe, coal and natural gas are the most used fuels in this sector, though electricity, fuelwood/charcoal and, to a lesser extent, petroleum products are also used. In 1992, approximately 20 per cent of Lithuanian households utilized coal as their main heating fuel. In Poland and Estonia, this figure amounted to approximately 50 per cent and 10 per cent, respectively. Figure III provides further details for Poland, the Czech Republic and Estonia.

21. Non-OECD European countries are undergoing a transition from largely centrally planned economies to a greater reliance on market forces. For households, this has meant higher energy prices and/or shortages of energy, especially during winter months when demand is high, though policies aimed at individual demand have not been the main thrust of policy measures in these countries. Rather, improving the efficiency of centralized equipment and distribution systems has been the focus of efforts in many of these countries. The installation of metering systems has been initiated but tariff restructuring to rationalize demand has not been initiated in most non-OECD European countries.

C. Developing countries

22. Developing countries are expected to realize a rapid growth in energy consumption both on a per capita basis and at the absolute level as their economies grow, incomes increase, lifestyles change and households switch from non-commercially traded fuels to modern energy services. Figure I shows per capita household energy consumption having remained relatively constant since 1970 in most developing regions. However, owing to population increases, total household energy consumption has increased throughout this period in all developing regions.

23. Figure I, showing residential energy consumption by energy type, indicates that sub-Saharan Africa, containing 12 per cent of the 1997 world population, uses mainly fuelwood and charcoal. Developing countries in the Asian and Pacific region, which constitute 54 per cent of the 1997 world total population, use largely fuelwood/charcoal, though some coal and petroleum products are also utilized by households. In Asia, as much as 70 per cent of the population live in rural areas needing fuelwood and depending on the integrity of the environment for basic necessities. In addition to fuelwood, 350 million tons of crop residue and 400 million tons of dung are burned annually. The Latin American and Caribbean region, containing 6 per cent of the 1997 world population, also uses mostly fuelwood/charcoal but petroleum products, natural gas and electricity are used as well.

24. The trend towards urbanization in developing countries accelerates increases in household energy consumption, and changes in lifestyles and habits associated with economic growth and urbanization have also contributed, and will continue to contribute, to increases in household sector energy use in developing countries. In 1995, the United Nations estimated that 46 per cent of the world's population (2.6 billion) resided in urban areas, and this figure is expected to increase to 50 per cent in 2006 and become more than 60 per cent by 2030. By 2030, developing countries are expected to house 80 per cent of the world's urban population and 86 per cent of the world's total population compared with 66 per cent and 79 per cent, respectively, in 1995. Urban lifestyles are associated with greater per capita energy use as more energy services for cooking, lighting, heating and cooling are demanded, and as the incidence of commercially traded energy use in developing countries increases.

25. More than 2 billion people, mostly located in rural areas of developing countries, live without access to modern energy sources. Their use of firewood, charcoal, biomass, including crop residues, and animal dung is mostly for cooking purposes, and their choice of fuel depends upon availability in the local area. Recent studies indicate that, as income increases, the type of energy used by rural households changes. In areas where annual per capita income is less than $300, 90 per cent of the people use traditional fuels for cooking.[11] As incomes increase above that level, to between $1,000 and $1,500 per year, households tend to rely entirely on conventional fuels. Also, since non-commercial fuels are typically not counted in energy balances and statistics, as households switch to these services significant increases in household energy use will be recorded. The concept of an "energy ladder", whereby households move from least efficient fuels to more efficient fuels as incomes increase and economic growth is realized, may be useful in predicting trends in energy use in the household sector in many developing countries.[12]

26. A recent survey of rural households in South Africa showed that the majority of households used a number of different fuels to satisfy their energy needs, even among those with access to electricity.[13] In fact, among those with access to electricity, only the high-income households relied mostly on electricity and this category represented only 14 per cent of electrified households. Consumption and income patterns generally fit the energy ladder concept but there was a higher incidence of multi-fuel use in middle-income rural households than expected. Also, access to electricity accelerated the move to more efficient fuels in rural-area households.

27. Though demand for energy by the household sector is rather inelastic with respect to price in industrialized countries, the effect of price is difficult to assess in developing countries. Thus, the impact of price-related polices such as taxes and subsidies in developing countries is uncertain without further study. Many basic services utilized by the household sector in developing countries, including energy, have been subsidized as a matter of social policy. However, many countries are re-examining such policies, noting that they lead to overconsumption and that they tend to benefit the middle and wealthy classes far more than the poorest strata of society. Other social policy measures may be more appropriate and more effective than energy subsidies. Recent investigations show that elimination of subsidies aimed largely at households in eight developing countries and economies in transition resulted in significant benefits to the environment.[14]

28. Renewable energy technologies may offer a solution for households in many areas where modern energy services are costly, especially rural and remote areas with widely dispersed populations. These technologies include mini- (and micro-) hydroelectric systems, solar systems (photovoltaic and solar thermal), wind energy, modern biomass including biogas systems, and geothermal systems. The feasibility of application of different renewable technologies often depends on locality and availability of energy resources as well as social factors. A recent assessment of solar cookers, for example, found that widespread adoption in appropriate areas could reduce deforestation, improve health conditions and improve the quality of life, especially of women, in many rural and remote areas.[15] However, certain cultural barriers, including food preparation methods, and misconceptions about solar cookers would have to be overcome.

III. Residential energy use and environmental issues

29. Environmental issues associated with residential use are closely linked to electricity in industrialized countries, countries in transition and, to some extent, developing countries. Electricity meets the need for lighting and powering appliances, as well as for water and space heating. Further increases in the demand for energy services in the residential sector in developing countries are expected to be satisfied with expanded electricity capacity. Environmental implications depend on many factors including the fuel type selected. Fossil fuels, nuclear fuels and hydropower can be used to generate electricity, each with vastly different environmental impacts. Also there is a range of impacts from the local level to the global level, depending on plant type and size. Decisions made in the electricity sector require long-term investments, and careful consideration of environmental impacts is important in the decision-making process.

30. Options for reducing carbon dioxide (CO_2) and other emissions in the electricity industry identified by the Intergovernmental Panel on Climate Change (IPCC) include achievement of greater efficiency by improving existing facilities with high-efficiency systems, the introduction of combined cycle power systems, and the improvement of boiler systems.[16] Also, using technologies to facilitate the co-generation of electricity and steam would lessen emissions as well as improve the operation and maintenance of systems, as would the introduction of photovoltaics, especially for local generation, and the use of fuel cells. A greater reliance on hydroelectric facilities where feasible would have a positive effect on emissions but might result in local land degradation and other social and environmental externalities. Other non-fossil fuel options include the expansion of nuclear power plants, the development of geothermal projects and wind turbines and the expansion of sustainable biomass combustion. In addition, the replacement of scrubbers and other energy-consuming technologies with more energy efficient emission control is recommended by IPCC.

31. Electricity use in the residential sector is associated with varying effects on the environment depending on the source of power for generation. Norway, for example, where 70 per cent of produced electricity is used in the residential sector, utilizes hydroelectric facilities to generate 100 per cent of its electricity. Its electricity consumption was not associated with emissions until recently when it began importing electricity from Denmark, where electricity is mainly generated with coal and has significant CO_2 emissions.[17] (To ensure that consumers pay the full environmental cost of electricity generated by coal, and to encourage conservation, taxes on electricity are now under consideration in Norway.)

32. In developing countries with large populations currently consuming relatively low levels of commercial energy in the residential sector, and that are expected to experience significant economic growth, such as China and India, decisions about how to satisfy growing residential energy demand will have an impact on local and global environmental decisions. Electricity consumption in the residential sector has increased in most developing countries, as shown in table 3. Significant increases in consumption during the five-year period from 1991 to 1996 have been recorded in highly populated countries including Bangladesh, China, Ethiopia, India, the Republic of Korea and Thailand, as well as in Chile, Israel, Jordan, Malaysia, Myanmar and Nepal.

33. Developing countries rely to a large extent on thermal power plants for their electricity generation, as illustrated in table 3, though many of those with hydro potential do utilize it for electricity generation purposes. In Africa, Côte d'Ivoire, Ghana, Kenya, Madagascar, Malawi, Mali, the Sudan, Zambia and Zimbabwe rely on hydroelectricity to meet most of their electricity demand. In South America, hydroelectric power satisfies most of the electricity demand in Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Paraguay, Peru, Uruguay and Venezuela; and in Asia, it is used to a significant extent in China, India, Nepal, Pakistan and Sri Lanka. Nuclear power facilities are used in several countries, and electricity generated from geothermal energy accounts for a small percentage of total electricity generated.

Table 3
Electricity consumption and generation type in selected countries

Country	Household electricity consumption (millions of kilowatt hours)			Total production (millions of kilowatt hours), 1996				
	1991	1966	Percentage change	Nuclear	Hydro	Geothermal	Thermal	Total
Algeria	4 000	4 760	19		130		20 524	20 654
Bangladesh	2 292	4 411	92		739		11 665	12 404
Barbados	426	520	22				650	650
Bolivia	986	1 410	43		1474		1 742	3 216
Botswana	185	245	32				757	757
Brazil	101 474	137 625	36	2 429	261 939		9 457	273 825
Brunei Darussalam[a]	622	805	29				1 575	1 575
Bulgaria	12 950	16 821	30	18 000	2 400		22 316	42 716
Burundi	80	87	9		118		2	120
Central African Republic	42	40	-5		82		22	104
Chile	5 281	9 950	88		18 862		12 416	31 278
China	135 240	240 000	77	13 620	187 966		879 724	1 081 310
Colombia	19 174	23 844	24		34 638		9 967	44 605
Costa Rica	2 440	3 035	24		3 630	470	753	4 853
Côte d'Ivoire	678	679	0		1 108		810	1 918
Croatia	5 801	7 391	27		7 228		3 320	10 548
Cuba	5 526	5 623	2		112		13 124	13 236
Cyprus	1 434	1 868	30				2 592	2 592
Dominican Republic	2 722	3 601	32		2 103		4 744	6 847
Ecuador	3 595	4 715	31		7 500		1 760	9 260
El Salvador	1 350	2 084	54		1 883	431	1 138	3 452
Estonia	3 185[b]	2 816	-12		2		9 101	9 103
Ethiopia (including Eritrea)	307	559	82		1 507	70	98	1 675
Fiji	89	103	16		430		115	545
Gabon[a]	477	473	-1		728		221	949
Ghana[a]	432	420	-3		6 625		6	6 631
Grenada	47	69	47				95	95
Guatemala	1 319	1 970	49		2 339		1 161	3 500
Haiti	177	162	-8		255		378	633
Honduras	1 019	1 318	29		2 585		230	2 815
Hungary	17 266	18 438	7	14 180	207		19 830	34 217
India	115 836	170 850	47	8 000	73 515	156	350 668	432 339
Israel	13 081	20 894	60		24		32 442	32 466
Jamaica[a]	1 435	1 945	36		128		5 910	6 038
Jordan	2 093	3 349	60		22		6 036	6 058
Kenya	989	1 275	29		3 120	290	335	3 745

Country	Household electricity consumption (millions of kilowatt hours)			Total production (millions of kilowatt hours), 1996				
	1991	1966	Percentage change	Nuclear	Hydro	Geothermal	Thermal	Total
Korea, Republic of	40 969	82 814	102	73 924	5 201		148 429	227 554
Latvia	3 537[b]	2 567	-27		1 860		1 263	3 123
Macao, China	663	1 220	84				1 620	1 620
Madagascar[a]	89	92	3		425		258	683
Malawi[a]	319	505	58		855		19	874
Malaysia	11 468	20 140	76		5 139		47 861	53 000
Mali	106	113	7		212		123	335
Mauritius	391	643	64		103		1 152	1 255
Mexico	41 901	50 462	20	7 878	31 692	5 734	117 222	162 526
Morocco[a]	4 338	5 100	18		765		11 413	12 178
Myanmar	932	1 565	68		1 630		2 626	4 256
Nepal	296	535	81		1 154		64	1 218
Nicaragua	838	944	13		355	600	964	1 919
Niger[a]	146	162	11				177	177
Pakistan	20 272	29 534	46	483	23 206		33 257	56 946
Panama	1 808	2 610	44		3 003		955	3 958
Papua New Guinea[a]	470	475	1		495		1 295	1 790
Paraguay	1 574	3 350	113		48 033		167	48 200
Peru	6 385	5 541	-13		16 528		3 510	20 038
Philippines	12 026	15 800	31		6 616	6 100	22 059	34 775
Poland	45 818	42 396	-7		3 910		135 880	139 790
Romania	13 356	12 889	-3	1 386	15 755		44 209	61 350
Russian Federation	208 355[b]	265 800	28	99 000	165 000	30	583 170	847 200
Senegal	189	185	-2				1 160	1 160
Seychelles	29	34	17				128	128
Sri Lanka	1 784	2 110	18		3 249		1 117	4 366
Sudan	695	728	5		946		392	1 338
Thailand	23 584	42 709	81		7 341	1	84 125	91 467
Trinidad and Tobago	1 206	1 259	4				4 541	4 541
Tunisia	2 337	3 526	51		67		7 770	7 837
Uruguay	2 592	3 655	41		6 199		467	6 666
Venezuela	21 534	26 233	22		56 000		18 968	74 968
Zambia	2 000	2 010	1		7 755		40	7 795
Zimbabwe	3 395	4 075	20		2 167		5 652	7 819

Source: Department of Economic and Social Affairs of the United Nations Secretariat, Energy balances electricity profiles, 1996 (New York, 1999).

[a] Estimate.

[b] Data for 1992.

34. In rural areas of developing countries, fuels currently used in the household sector are often associated with adverse health and environmental impacts (see report of the Secretary-General on the development and implementation of rural energy policies (E/C.13/1998/5) of 3 February 1998). The burning of firewood and dung emits carbon monoxide, particulate matter and other pollutants that are responsible for a variety of health problems including bronchitis, emphysema and other respiratory diseases, which contribute to higher mortality rates. Generally, infants and children are diversely affected, as acute respiratory infections, which cause approximately 4 million deaths each year, are at least partially attributable to smoke inhalation. Use of dung as a fuel rather than fertilizer may also reduce nutrients available in the soil. One recent study found that the use of 400 million tons of dung for energy purposes in Asia could have been used to fertilize enough soil to contribute 14 million additional tons of grain.[18]

Table 4
Comparison of air pollutant emissions of various stove types
(kilograms per unit of energy delivered)

Fuel uses and scale (efficiency)	*Amount equivalent to 1 million megajoules (MJ) delivered*	*Particulates*	*Sulphur oxides*[a]	*Nitrogen oxides*	*Hydrocarbons*	*Carbon monoxide*
Residential heating stoves (less than five kilowatts)						
Wood (tons) (50 per cent)	130	2 700	30	100	6 800	17 000
Anthracite (tons) (65 per cent)	49	48	200	250	100	1 000
Bituminous (tons) (80 per cent)	53	550	1 100	270	530	5 300
Distillate oil (liters) (90 per cent)	33 000	11	1 200	71	4	20
Natural gas (cubic metres (m^3)) (90 per cent)	30 000	7	negative	38	4	10
Cooking stoves						
Tropical wood (tons) (15 per cent)	420	3 800	250	300	3 200	34 000
Cow dung (tons) (15 per cent)	530	10 000	3 200	7	?	44 000
Indian coal (tons) (20 per cent)	220	280	2 200	460	2 200	27 000
Coconut husk (tons) (15 per cent)	480	17 000	?	7	?	54 000
Natural gas (m^3) (80 per cent)	32 000	1	negative	10	5	250

Source: United Nations Development Programme, *Energy After Rio* (New York, 1997).
[a] Sulphur emissions from fossil fuel vary widely depending on fuel quality.

35. Table 4 indicates the emissions from various types of residential heating stoves and from cooking stoves often used in developing countries along with an efficiency rating for each type of stove. Natural gas is the most efficient fuel listed and emits the least amount of each pollutant in almost every category. Solar cookers, not listed in table 4, also have the potential to provide heat for cooking in some areas without adverse environmental effects.

36. The use and overuse of wood fuels have negative environmental effects, namely, with respect to deforestation, especially in sub-Saharan Africa. Though evidence exists that some wood fuel is gathered in non-forested areas, *inter alia*, along roadsides and next to fields and houses, fuel gathering is a major cause of deforestation in some areas, including sub-Saharan Africa, especially where fuelwood is used for charcoal production.[19] Two out of three developing countries face fuelwood shortages and in some countries, such as the United Republic of Tanzania and Haiti, areas particularly hard hit by deforestation have been described as "scorched-earth" areas. Often these areas supply fuelwood for thriving commercial charcoal suppliers to urbanized or semi-urbanized areas. Furthermore, deforestation has direct implications for the time required to gather wood for household use in rural areas and a negative impact on the use of time and quality of life of women and children who undertake this task. This and other negative social impacts of deforestation on local populations are also important considerations in determining how to best provide energy for residential use with minimal adverse environmental effects so as to achieve the goal of sustainable development.

IV. Conclusions and recommendations

37. Although per capita energy consumption in the residential sector has been decreasing in industrialized countries and has levelled off in developing countries, total consumption is expected to increase as population increases, especially in developing countries. Other factors affecting demand include income, lifestyle, cultural habits, household size and climatic conditions, many of which are expected to contribute to increased demand in this sector in developing countries as they experience economic growth. The trend towards smaller households, with fewer members, in many countries will lead to increases in per capita energy demand.

38. There is evidence that a saturation in appliance and household energy use has been reached in many industrialized countries. Efficiency gains may be realized as consumers trade old appliances for new ones, if improved standards on new appliances are applied and enforced.

39. Consumers in industrialized countries appear not to be highly responsive to price changes, indicating that regulations, standards and labelling may be more effective than price policies in curbing demand, reducing emissions and ensuring that environmental goals are met in these countries, especially for electricity. Since household appliance prices appear to have greater influence over consumer decisions than electricity prices, policy makers may wish to target appliance prices when considering subsidies and taxes as a means to curb household demand for energy.

40. Demand-side management policies have been successful in curbing residential energy demand and promoting energy efficiency in this sector in some countries. These measures include dissemination of information, raising consumer awareness

about energy efficiency products, voluntary and compulsory standards on appliances and equipment, and labelling. Governments should consider such policies especially when undertaking deregulation of the electricity industry, which is expected to lower electricity prices.

41. Local governments have a role to play in setting and enforcing building codes that ensure energy efficiency in residential and other buildings. In localities served by district heating, efforts should be undertaken to improve efficiency of these systems and national Governments may wish to assist if local financing is unavailable.

42. A significant portion of households in rural areas in developing countries rely on sources of energy that are not commercially traded to meet cooking, lighting, water heating and space heating needs. Thus, they are often not considered in energy balances and subsequent analyses, and may be overlooked by decision makers. As socio-economic conditions improve, switching to more efficient fuels occurs and total energy use increases in this sector. Renewable energy technologies may be appropriate in many rural areas to meet household needs and such technologies often provide energy services with minimal environmental effects. However, incentives by Governments such as soft-term consumer loans, subsidies and various incentives to the private sector may be required to initiate renewable energy programmes in rural areas.

43. Investment decisions in the electricity industry have long-term implications for the environment, and such decisions should be made with all environmental costs and risks included in cost/benefit and accounting analyses undertaken to assist in the decision-making process. Countries undergoing privatization of their electricity industries should ensure that appropriate environmental regulations are in place and properly enforced.

44. The adoption of cleaner technologies for electricity generation should be encouraged at the national, regional and international levels.

Notes

[1] See *Official Records of the Economic and Social Council, 1999, Supplement No. 12*, (E/1999/32, chap. I, sect. B, draft decision II.

[2] L. Schipper, F. Unander and C. Marie-Lilliu, *The IEA Energy Indicators Effort: Extension to Carbon Emissions as a Tool of the Conference of Parties* (Paris, International Energy Agency, 1999).

[3] M. Colombier and P. Menanteau, "From energy labelling to performance standards: some methods of stimulating technical change to obtain greater energy efficiency", *Energy Policy*, vol. 25, No. 4 (1997), pp. 425-434.

[4] United States Department of Energy, *Residential Energy Consumption: Two Decades*, 1997.

[5] Percentage of households using liquefied petroleum gas (LPG) and wood for heating purposes remained the same at 4 per cent and 2 per cent respectively.

[6] R. Haas and others, "Impacts on electricity consumption of household appliances in Austria: a comparison of time series and cross-section analyses, *Energy Policy*, vol. 26, No. 13 (1998), pp. 1,031-1,040.

[7] I. Matsukawa and N. Ito, "Household ownership of electric room air conditioners", *Energy Economics*, vol. 20 (1988), pp. 375-387.

[8] Runa Nwsbakken, "Price sensitivity of residential energy consumption in Norway", *Energy Economics*, vol. 21 (1999), pp. 493-515.

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[12] United Nations Development Programme (UNDP), Department of Economic and Social Affairs of the United Nations Secretariat and World Energy Council (WEC), *World Energy Assessment* (forthcoming), chap. 10.

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[14] K. Varangu, "Global energy trends and sustainable development: an IEA perspective", presented to the first session of the Ad Hoc Open-Ended Group of Experts on Energy and Sustainable Development, New York, 6-10 March 2000.

[15] M. Tucker, "Can solar cooking save the forests?", *Ecological Economics*, vol. 31, No. 1 (1999), pp. 77-89.

[16] World Meteorological Organization/United Nations Environment Programme, *Climate Change: The IPCC Response Strategies* (1990).

[17] R. Nesbakken, "Price sensitivity of residential energy consumption in Norway", *Energy Economics*, vol. 21 (1999), pp. 493-515.

[18] K. Miller and L. Tangley, *Trees of Life: Saving Tropical Forests and Their Biological Wealth*, (Boston, Massachusetts, Beacon Press, 1991).

[19] *World Energy Assessment* ..., chap. 3.

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Review of salient trends and issues on energy development and use in the context of sustainable development: renewable sources of energy, with emphasis on solar energy

Renewable sources of energy, with emphasis on solar energy

Report of the Secretary-General

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I. Background and introduction

1. Although the source of all renewable energy is solar energy, a distinction is often made between direct solar energy and its indirect forms, such as hydro, wind, biomass, ocean waves and thermal gradients. The present report summarizes the current status and relevant technical, economic, social, and environmental issues pertaining to the development and application of the direct form of solar energy, as well as policy options for stimulating its wider-scale utilization.

2. The real importance of solar energy in providing a sustainable supply goes far beyond its present contribution. It is the most widely distributed resource; its technical potential for power generation, even at present levels of technology, is many times that of other renewable sources. At present, the total contribution of the "new renewables" to world energy consumption is only about 2 per cent. The bulk of this can be accounted for by power generation based on wind, geothermal and biomass sources and by the use of biomass-derived gaseous and liquid fuels. No clear estimate of the contribution of direct solar energy to the world energy supply is available, but it is probably not more than 0.1 per cent.

3. The prospects for solar energy's providing many modern energy services in the medium and long terms are excellent. In order for it to be a major contributor to the global energy supply, there are still many issues, such as conversion technology, cost, land requirement, and storage aspects, that will have to be dealt with in a comprehensive manner. Nevertheless, there are several applications for which solar energy is an attractive and viable option even today; the list is expected to grow in future. With further technological developments, improved economics and greater user acceptance supported by suitable fiscal and policy measures, solar energy could become a major energy provider by 2050. In certain developing-country situations, the impact could be felt even sooner.

II. Solar energy resource

4. At the aggregate level, the solar energy resource base is very large (the solar energy intercepted by earth is 5.5 million exajoules (EJ)/year) compared with total global energy consumption (435 EJ/year). Even if a small fraction of this is converted into useful energy, its magnitude could be over 100 times the present level of energy consumption.

5. Solar radiation data is available for thousands of locations all over the world, often compiled over several decades. Numerous handbooks and atlases for many countries and regions have been published. The World Radiation Data Centre maintained for the World Meteorological Organization (WMO) by the A. I. Voeikov Main Geophysical Laboratory in Saint Petersburg, Russian Federation, together with the National Renewable Energy Laboratory of the United States of America, offers an on-line archive of solar radiation data from over 1,000 sites throughout the world from 1964 to 1993. The archive includes data on direct and diffuse solar radiation and sunshine duration.

6. It is possible to calculate the energy density, that is to say, the amount of energy available per unit area and per unit time for most places on earth using the available data, and software has been developed for this purpose. Nevertheless, there are areas in Africa and South America that are not adequately covered by data-

collection centres. Furthermore, it is advisable to obtain precise data at a particular location for an extended period of time if large power projects are to be undertaken at that location.

7. The practical utilization of solar energy requires the transfer of the heat to a liquid or gas (the solar thermal route) or direct conversion of sunlight into electricity (the photovoltaic (PV) route). The amount of usable energy that can be obtained through these routes and the applications that can be served depend not only on the efficiencies of these technologies but also on certain factors inherent in the nature of the resource itself.[1] The following are the main factors:

(a) Time variation: the solar flux at a given point varies hourly, monthly and seasonally from a minimum of 0.2 kilowatt (kW)/square metre (m^2) to a maximum at the surface of about 1 kW/m^2 necessitating the use of storage;

(b) Geographical variation: the yearly insolation (that is to say, energy density) varies from about 800 kilowatt hours (kWh/m^2 in northern Scandinavia and Canada to about 2,500 kWh/m^2 in the North African desert, implying differences in performance of solar devices at different locations;

(c) Weather conditions: the annual average sky clearness is in the range of 80-90 per cent in sunny belts and only 40-50 per cent in Europe and Japan. Low sky clearness necessitates additional storage or larger system sizes.

8. Several factors suggest an increased role for solar energy in the world energy scene:

(a) Solar energy is more dependable and available at far more locations than any other energy source. Global variations in annual insolation levels are less than for wind energy. Also, for a given site, the yearly fluctuation in solar energy is small compared with that of wind energy and hydropower resources;

(b) The contribution of solar energy can actually come from millions of small and medium-sized systems all over the world, rather than from a few hundred or a few thousand large systems. In addition, using land where it is available, solar systems can also be installed on rooftops and along highways;

(c) PV systems are ideally suited for small, decentralized power supply to meet the lighting, drinking water, health, education and entertainment needs in large areas not yet served by conventional electricity grids. This can translate into electricity benefits (or at least initial electrification) for up to 2 billion additional consumers. Such coverage of the energy supply system is in fact viewed as an essential feature of energy for sustainable development.

III. The photovoltaic route: status of technology and utilization

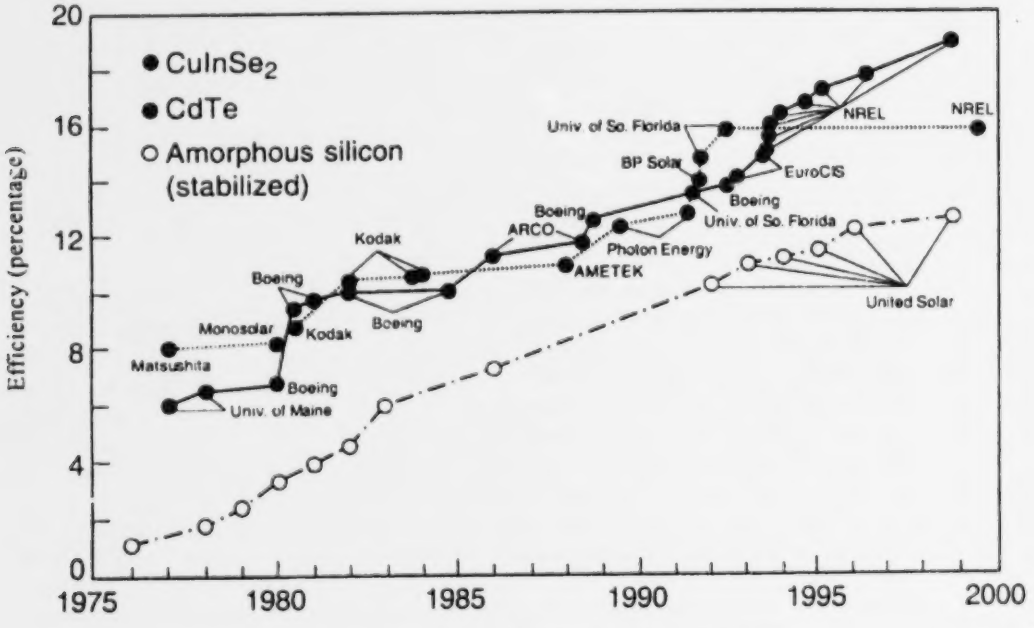
9. Solar PV technology enables the direct conversion of sunlight into electricity without any moving parts, noise or pollution. Conversion is achieved through a device known as a solar cell. Solar cells are devices that are made from certain semiconducting materials that have the right optical and electronic properties to enable them to absorb solar radiation and generate a current. In actual practice, a

[1] United Nations Development Programme, *Energy After Rio: Prospects and Challenges* (UNDP, 1997).

number of solar cells are interconnected and encapsulated to form a module. Modules come in various sizes, and voltage and power ratings, and constitute the building block of a solar PV system.

10. During the past 40 years, solar cells have remained the preferred and most reliable power source for satellites. In addition to silicon, other materials, notably gallium arsenide, have been used for this purpose. While silicon cells had been quickly adapted for terrestrial applications and the costs brought down by a factor of 10-20 during the 1970s and 1980s, the cost of gallium arsenide cells remained too high for terrestrial applications. The search began, however, for alternative materials and techniques, notably in the thin-film form. Among the materials that have been found promising are amorphous silicon (a-Si), polycrystalline silicon films, cadmium telluride (CdTe) and copper indium diselenide ($CuInSe_2$) (referred to commercially as CIS, or CIGS when gallium is also added). While a-Si has been in commercial production since the early 1980s, the other materials have witnessed major improvements in efficiencies and manufacturing processes during the 1990s. The efficiency records set by different research groups for these materials over the past two decades are shown in the figure.

Figure
Efficiencies of thin-film solar cells



Note: BP: British Petroleum; NREL: Natural Renewable Energy Laboratory.

11. Typically, commercial solar cells/modules have efficiencies that are about one half of those achieved in the laboratory (usually for a smaller cell size). Data for selected materials/technologies are given in table 1.

Table 1
Status of some important solar cells and module technologies

Technology	*Best laboratory cell efficiency (percentage)*	*Typical efficiency of commercial modules[a] (percentage)*
Single crystal silicon	24.7	13-15
Multi-crystalline silicon	19.8	12-14
Polycrystalline silicon films	116.6	(8-11)
Amorphous silicon	13.5	6-9
Copper indium/gallium diselenide	18.8	(8-11)
Cadmium telluride	16.0	(7-10)
Concentrator cells	33 (tandem)	-
	28 (single)	

Sources: M. A. Green and others, "Solar efficiency tables (Version 12)", *Progress in Photovoltaics: Research and Applications*, vol. 7 (1998), pp. 31-37; and the Photovoltaic Solar Conference (PVSEC)-11 Conference information.

[a] Figures in parentheses referring to pilot production or first commercial production.

12. The module efficiency figures in the table are for the flat-plate type. Concentrator modules normally employ high-efficiency cells and are mounted on structures that track the sun so that the concentrated beam always falls on the cells; flat-plate modules, on the other hand, may or may not employ tracking arrangements.

13. World PV production has been increasing at impressive rates during the past decade as indicated in table 2. Growth over the last three years has been particularly impressive, with global production at the end of 1999 having reached 200 MW. Single-crystal and multi-crystalline silicon cells accounted for over 80 per cent of this production. Production for the different cell technologies is given in table 3. In a number of countries beyond Europe, Japan and the United States of America, production has been confined to modules only, using cells imported from Europe or the United States of America. Exceptions in this regard are Australia, Brazil, China, India, Mexico and South Africa.[2] The size and configuration of PV systems vary with the application. The commonest applications are lighting, water pumping, and rooftop or ground-based power systems that feed electricity to the grid. Many applications over a broad range are considered commercially viable, in other words, users buy PV systems in preference to available alternatives on the grounds of economics or convenience. These include telecommunications, railway signalling, broadcasting, remote-area power, recreational vehicles and military applications, as

[2] G. L. Morrison and B. D. Wood, "Packaged solar water heating technology: twenty years of progress", World Solar Energy Congress, Jerusalem (1999).

well as consumer products such as calculators and watches. Distribution among the various applications for the 1990s is given in table 4.

Table 2
World photovoltaic module production, 1990-1999
(MW)

Year	*United States*	*Japan*	*Europe*	*Rest of the world*	*Total*
1990	14.8	16.8	10.2	4.7	46.5
1991	17.1	19.9	13.4	5	55.4
1992	18.1	18.8	16.4	4.6	57.9
1993	22.44	16.7	16.55	4.4	60.09
1994	25.64	16.5	21.7	5.6	69.44
1995	34.75	16.4	20.1	6.35	77.6
1996	38.85	21.2	18.8	9.75	88.6
1997	51.0	35.0	30.4	9.4	125.8
1998	53.7	49.0	31.8	18.7	153.2
1999	64.6	80.0	36.4	20.5	201.5

Sources: *PV News*, vol. 19, No. 2 (February 2000), and yearly February editions.

Table 3
1999 world cell/module production by cell technology

Technology	*Module production (MW)*	*Percentage of total*
Single-crystal silicon	73.2	36.3
Multi-crystalline silicon	88.4	43.9
Amorphous silicon	23.9	11.9
Crystalline silicon concentrators	0.5	0.25
Ribbon silicon	4.2	2.1
CdTe	1.2	0.6
Polycrystalline silicon thin films	2.0	1.0
a-Si on silicon wafers	8.1	4.0
	201.5	**100.00**

Sources: PV News, vol. 19, No. 2 (February 2000); and yearly February editions.

Table 4
World module shipments by market sector
(MW)

Market sector	*1990*	*1993*	*1996*	*1997*	*1998*
Consumer products	16	18	22	26	30
United States off-grid residential	3	5	8	9	10
World off-grid rural	6	8	15	19	24
Communications/signal	14	18	23	28	31
PV/diesel commercial	7	10	12	16	20
Grid-connected	1	2	7	27	36
Central power	1	2	2	2	2
Total	**48**	**63**	**89**	**127**	**153**

Source: Paul Maycock, "Economic PV: a shift in thinking", *Renewable Energy World*, vol. 2, No. 5 (September 1999), pp. 73-76.

14. Nearly 40 MW of the modules shipped in 1998 were used to power small electronic devices with PV modules of less than five watts (W).[3] Besides millions of calculators and watches powered by energy from indoor light, there are 20 million battery trickle chargers and 300,000 electric fence chargers, and 2 million garden lights, 200,000 auto ventilators, and 100,000 pith helmets and caps. It is estimated that over 400,000 homes in developing countries have a minimum PV system that provides power for lights and in some cases also a television set.[4]

15. The cumulative world production of terrestrial PV products over the past quarter century is estimated to have been between 1,100 MW and 1,200 MW. Assuming that 1,000 MW of this is currently installed and in operation, and assuming further that each kW of PV modules generates an average of 1,200 kWh per year of usable energy, the PV systems installed so far have the capacity to generate 1.2 billion kWh/year. This may save some 12 million tons of carbon dioxide CO_2 per year. Both numbers are insignificant in the present world energy scenario.

16. The intense research and development (R&D) activities in the field of photovoltaics have a bearing not only on their economics, but also on new applications, market development and user acceptance. The R&D efforts cover new materials and production techniques as well as improvements in the balance-of-system (BOS) components. For example, impressive improvements have been reported on organic dye solar cells.[5] A research group in Switzerland has established links with industrial organizations in a few countries with a view to commercializing this technology. Another recent effort relates to the development of alternating current (ac) modules, which possess built-in inverters so that the modules deliver readily usable ac power. These modules can be useful in roof-mounted installations

[3] Paul Maycock, "Economic PV: a shift in thinking", *Renewable Energy World*, vol. 2, No. 5 (September 1999), pp. 73-76.

[4] Ibid.

[5] D. Meissner, "Plastic solar cells", *Photon International*, No. 2 (1999), pp. 34-37.

and potentially also in power plants. Field testing of such modules is currently under way at many locations in the United States of America.[6]

17. In most small PV systems, storage batteries constitute the second most expensive item after the modules. Lead-acid batteries continue to be the most commonly used storage devices for PV energy. During the past 15 years, lead-acid batteries with low maintenance and longer life have been developed. Such "solar batteries" are now available in several countries. Another variant of the lead-acid battery is a sealed version that is totally maintenance-free. Such batteries are popular in portable systems as well as in locations that are difficult to access. They are, however, more expensive than low-maintenance batteries and may not have an equally long life cycle. In certain low-power applications, the nickel cadmium battery, which is relatively inexpensive, finds use but only on a limited scale. Further research is needed to develop alternative electrical energy storage systems that can reduce the cost of storage.

18. The control electronics associated with PV systems, such as charge controllers and inverters, requires special attention. Many PV system failures (in addition to lack of battery maintenance) are often traced to the unsatisfactory performance of these components in actual practice. However, significant improvements in power electronics during the past decade have led to a range of reliable, high-quality and compact inverters. These inverters offer direct current (dc)-to-ac conversion efficiencies in excess of 90 per cent. Inverters can also be made grid-synchronous for use in PV systems that are linked to the electricity grid. A special type of inverter is used to operate ac pumps directly from the PV array. Large-volume production has led to significant reduction in the cost of the electronics.

IV. The thermal route: status of technology and utilization

19. The solar thermal route, which utilizes the heat in solar energy, is in some ways less sophisticated than the PV route. While the processes and applications are different, this technology also has the same advantages of silent and pollution-free operation and system modularity. Like the module in a PV system, a collector is the building block of a solar thermal system.

A. Solar water heating

20. The commonest use of solar thermal technology is in heating water. This is now considered to be a mature technology as well as one that is commercially viable. There is therefore no significant government funding for technology development or for promoting wider use. Certain policy measures have, however, been employed in some countries to encourage the use of solar water heaters.

21. Data on the worldwide production and use of flat-plate collectors are not compiled on a systematic basis as is the case for PV modules. Table 5 shows the number of solar domestic water heaters (SDWH) and the glazed collector area

[6] *CADDET Newsletter*, No. 1/00 (2000). (*Note*: CADDET: Centre for the Analysis and Dissemination of Demonstrated Energy Technologies.)

produced annually for some countries with reference to 1994, as published in a 1999 report.[7]

Table 5
Solar domestic water heater (SDWH) markets in 1994

Country	*Total SDWH in use (thousands)*	*Total glazed collector area installed (thousands of m^2)*	*Glazed collector area produced annually (thousands of m^2)*
Australia	350	1 400	140
Austria		400	125
Canada	12		
China		1 500	500
Cyprus		600	30
Denmark	14	74	8
France		260	18
Germany		685	140
Greece		2 000	120
Israel		2 800	300
Japan	3 800	7 000	
Korea, Republic of	8.7		50
Netherlands	10	49	9
Portugal		200	13
Spain		118	12
Sweden		71	20
Switzerland	9.3	131	6
United Kingdom	45	108	7.2
United States	1 200	4 000	70

Source: G. L. Morrison and B. D. Wood, "Packaged solar water heating technology: twenty years of progress", World Solar Energy Congress, Jerusalem (1999).

22. It can be seen that Japan has the highest production and total number of installations among all countries. Progress in European countries has also been remarkable. The industry in the United States of America, which installed such systems in thousands of homes during the 1970s and early 1980s, suffered a setback with the withdrawal of tax benefits. Solar systems are being used for district heating[8] as well as in stand-alone "combisystems", which provide residential hot water and space heating.[9]

[7] G. L. Morrison and B. D. Wood, "Packaged solar water heating technology: twenty years of progress", World Solar Energy Congress, Jerusalem (1999).

[8] J. Dalenbaeck, "Thinking Big: large-scale solar heating in Europe", *Renewable Energy World*, vol. 2, No. 4 (July 1999), pp. 86-91.

[9] W. Weiss, "Solar Combisystems: thinking big for a sustainable energy future", *Renewable Energy World*, vol. 3, No. 2 (2000), pp. 84-91.

23. According to another study covering most major user countries,[10] the total collector area installed by 1994 in the world amounted to 25.4 million m^2 with sales in 1994 amounting to 2.287 million m^2, of which the European Union (EU) accounted for about 5.46 million m^2, Japan 6.04 million m^2, the United States of America 5.2 million m^2 and Israel 2.8 million m^2. According to a recent estimate by the European Solar Industry Federation, sales of solar collectors in Europe in 1998 were of the order of 1 million m^2 and the total installed collector area in EU reached over 8 million m^2.[11] These systems are estimated to save 1.4 million tons of CO_2 annually.

B. District heating

24. Interest in large-scale solar water heating as a means of district heating has been increasing steadily in Europe. Such plants mainly serve residential areas. Some use large seasonal storage systems while others work in conjunction with biomass heating.[12] There are about 45 systems with a collector area of 500 m^2 or more, aggregating to 77,742 m^2. The oldest plant still in operation dates from 1983 and is located in Sweden. Sweden remains the leading country with 15 plants accounting for more than 35 per cent of the total installed collector area. The largest plant is in Denmark with a collector area of 9,040 m^2. It has been estimated that, in favourable cases, investment costs may come down to euro 250/m^2 of collector area, resulting in a solar heating cost of euro 0.06/kWh.

C. Solar cooking

25. It is estimated that about one half of the world's cooking is performed using firewood as the fuel. In certain regions of the world, cooking energy requirements place great pressure on biomass resources; the burning of biomass in traditional stoves also causes problems to users. Considering that the regions that depend on biomass for cooking also have significant levels of solar radiation, it would appear that solar cooking can have a beneficial impact in these regions. A number of cooker designs are available. The two most common are the box-type cooker, which is essentially a flat-plate collector in which two to four vessels containing the food to be cooked are placed in the box; and the small parabolic reflector, which concentrates the solar radiation onto a vessel placed in the focal region. A simple cooker of corrugated cardboard with one side pasted with a reflecting film has also been designed as a low-cost alternative. All these cookers are suitable for single-family use. Such cooking devices have certain limitations in regard to the type of preparations that can be made and the time required for the cooking. As a result, solar cookers can only supplement but not totally replace conventional fuels. A home that uses a solar cooker regularly can save between one third and one half of the conventional fuel that is otherwise used for cooking. The payback period is usually two to three years. Cookers with electrical back-up are also available.

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[10] *Opportunities for Large Solar Purchase of Active Solar Systems* (Harwell, United Kingdom, IEA ACDDET Centre for Renewable Energy, December 1998).

[11] R. Berkmann, "Promoting solar thermal: comparison and evaluation of experiences", *Renewable Energy World*, vol. 2, No. 4 (July 1999), pp. 93-95.

[12] *Technical Bulletin No. 120,* (Harwell, United Kingdom, IEA CADDET Centre for Renewable Energy, 1999).

26. Large concentrating cookers can also be used to cook meals for 30-40 persons twice a day. The world's largest solar cooking system has been functioning since February 1999 at Taleti in the Indian State of Rajasthan. The system employs 84 parabolic concentrators, each of 9 m^2 aperture area. Receivers placed at the focus of the concentrators are connected in series. Steam is generated in the system and is used for cooking food and boiling milk in the kitchen of the Brahmakumaris organization. The system can normally prepare meals for 10,000 persons twice a day. The consumption of diesel fuel otherwise used in the boiler system of the kitchen has been drastically reduced through use of the solar systems.

27. China and India are among several countries that have been promoting the use of solar cookers. About 450,000 box-type solar cookers have been distributed in India. A subsidy was made available initially for solar cookers for over 12 years. The subsidy was discontinued in 1994, although the Government continues to promote solar cookers through other measures.

D. Solar thermal power generation

28. A number of experimental projects have been undertaken all over the world since the 1970s to evaluate all three types of collector in concentrating systems and demonstrate their use for power generation. About 400 MW of such systems have been installed so far, the largest collection of which are located in California, United States of America, with an aggregate of about 350 MW. These power plants employ parabolic trough collectors. Some systems heat oil which in turn is used to generate steam; other systems employ natural gas as the secondary fuel. The California plants were completed in the late 1980s and early 1990s. Although technically successful, no more plants of this kind have been built, as they did not prove to be competitive in the absence of tax benefits and other fiscal incentives. A 140 MW solar thermal combined cycle power plant, employing parabolic trough collectors and naphtha as the supplementary fuel, has just been approved for installation in Mathania in Rajasthan, India. Besides funding from the national and State Governments in India, the project is receiving substantial assistance from the Global Environment Facility (GEF) and Kreditanstalt für Wiederaufbau (KfW) of Germany.

29. Dish systems can be used either with a Stirling engine or with a steam engine. Such systems have been tried in Australia, the United States of America and Spain, among other countries. The typical power output of a dish is in the range of 10-50 kW. Such systems have been projected as being suitable for meeting village and small community power needs. Further technical improvements and series production will be necessary to bring down the costs and improve reliability.

30. The largest project employing the solar tower or central receiver principle is a 10 MW system known as Solar Two in Barstow, California. The system uses molten salt as the heat transfer fluid. The relative economics of this type of system compared with the dish and parabolic trough systems have yet to be fully established. More demonstration and pilot projects based on all three collector technologies appear to be necessary.

31. At least two other approaches to solar thermal power generation have been tried: the solar pond and the solar chimney. Experimental pond projects were constructed in Israel and California, United States of America, during the 1980s. The ponds are no longer operational, as the economics are not favourable compared

with those of fossil fuel-based generation. The solar chimney employs the principle of the draught created by hot air rising up a very tall chimney surrounded by a large area covered with transparent material. Wind turbines placed at the base of the chimney generate electricity. Higher-power systems require taller chimneys and larger areas to heat the air. There is no operating power plant based on this concept at this time, although a small system was installed and evaluated in Spain during the 1980s.

E. Other solar thermal applications

32. Solar thermal energy can be used directly as heat for drying and for water desalination. Much research has been done on such systems all over the world. Solar drying systems have to be designed, keeping in mind the product to be dried, its initial and final moisture contents, the rate of drying required for the product and the geographical location. Because of these conditions, it is not possible to evolve standard designs for mass production and installation. Several successful installations have, however, been designed and built for specific agricultural products including tea, spices, vegetables and flowers. Solar drying may also be a feasible option in the confectionery, food processing, chemical and pharmaceutical industries.

33. Different designs of solar stills have been developed in many countries to distil water. While technically the systems are suitable in areas with brackish water, the economics are not yet favourable. Small stills, however, seem to be useful in providing distilled water for batteries in remote and unelectrified areas.

34. Solar thermal energy can also be used for water pumping, air conditioning and refrigeration. Such systems, however, are technically more complicated and less reliable compared with PV-based systems. There are also no clear economic advantages for such applications.

F. Solar buildings

35. A major area of activity all over the world relates to the use of solar energy in buildings. In recent years, there has been growing interest in solar passive architecture and in integrating solar PV systems in buildings. The design and construction of "solar buildings" are emerging as a new discipline in architecture and building construction.

36. Solar passive architecture is basically climate-responsive building design. The height and orientation of a building can be fixed in a manner that allows maximum use of solar light during the daytime. The size and placement of windows, overhangs and skylights can also determine the amount of solar heat that is allowed inside the building. A properly designed solar building can reduce the heating load in winter and the air-conditioning load in summer. The use of appropriate building materials, external cladding and insulating materials for walls can contribute further to reduction in the energy demand in buildings. Demonstrations have shown that new buildings can be 40 per cent more efficient and even the refurbishing of old

buildings can reduce energy consumption by 25 per cent in most Western European countries.[13]

37. It is not inconceivable that a building can be designed with appropriate architectural features and further fitted with active solar thermal and PV systems so that dependence on external energy inputs, especially for electricity and water, is nearly zero. Such experimental solar houses have been built by enthusiasts and by way of demonstration. Considering that buildings consume about 20 per cent of the total energy in many countries, the impact of this effort could be significant in the future.

V. Solar industry and international trade

38. As solar energy applications began to appear in the 1970s, the organized manufacture of solar collectors, PV modules and systems started in a few countries. Actually, there were a few manufacturers of solar thermal products even before the oil price increase of 1973. During the 1980s, commercial-scale manufacture spread to several countries on all continents.

A. Solar PV manufacturing

39. The PV sector attracted investments by large multinational companies, including a few oil companies. There are three clear stages or levels of manufacture in this sector: solar cells, PV modules and systems. The investments required to set up manufacturing facilities are highest for cells, followed by modules, and lowest for system assembly. The same order is perceived in respect of complexity of technology.

40. Solar cell manufacture has gone through many changes and improvements during the last two decades. The size of silicon cells increased and diffusion, contact formation and other process stages were refined. Thin-film solar cells required the development of wholly new processing techniques. Even today, thin-film production is based largely on custom-built equipment. An important trend is the progressive increase in automation. The "glass in-panel out" concept has resulted in manufacturing lines in which cells and modules are fabricated in an integrated fashion. The roll-to-roll deposition of some types of thin-film cells is also an example of automated production.

41. While efficiency improvements and larger throughputs can reduce the cost of the product, they often push up the cost of the capital equipment. Economies of scale are then needed to make production viable. For a production capacity of 1-2 MW of crystalline silicon cells, an investment of about US$ 2 million-US$ 3 million per MW is needed. At the 10 MW level, the cost per MW drops to one half. In the case of thin films, a 1 MW plant may cost as much as US$ 6 million-US$ 8 million, but a 10 MW plant may require only US$ 30 million. This trend is already known in the semiconductor and electronics industries.

[13] UNDP, Department of Economic and Social Affairs of the United Nations Secretariat and World Energy Council, *World Energy Assessment* (forthcoming).

42. The patterns of capital requirement and technological complexity have practically established the kind of manufacturing activity that can take place in a country. While industrialized countries can afford to set up increasingly larger plants that make solar cells, most developing countries have to be content with the assembly of systems and, in some cases, the manufacture of modules. Because of the size of their domestic markets, India and China have been able to develop and sustain solar cell manufacture.

43. The above pattern also reflects the cost of labour at different stages of PV production. Module production is more labour-intensive compared with cell production, and therefore multinational manufacturers sometimes find it cheaper to shift some stages of their manufacturing activities to developing countries. Manufacture and assembly of systems are also cheaper in developing countries that have some infrastructure in the battery and electronics industries.

44. Historically, the United States of America has had a 35-45 per cent share of the global PV module production. A major increase in PV manufacturing capacity is under way in Europe at this time.[14] By the end of this year, Europe will have a production capacity of 100 MW. Production in Japan and the non-European and North American regions increased significantly in the last two years.[15] In spite of these trends, United States of America industry hopes to retain a 40 per cent share of global module shipments between 2000 and 2020.[16]

45. Most of the global trade in photovoltaics also emanates from the three main producing regions: the United States of America, Europe and Japan. About 30 per cent of the United States of America production is used domestically, and the rest is exported. With the ongoing big programmes in Japan and Germany, much of the trade is within these three regions. The European Commission has targeted production of 1,000 MW under the Campaign for Take-off, of which 650 MW will be used within the EU countries and 350 MW exported.[17] Shell Solar plans to install 50,000 solar home systems in South Africa and 100,000 in China, using cells imported from their production facilities in Europe. Other major global exporters include Siemens, BP Solarex, Photowatt, Kyocera, Sanyo, Helios, and Astropower. Exports of Indian-made cells and modules have also been increasing steadily; exports during 1999-2000 amounted to about 6 MW.

46. Growth in PV markets has also led to growth in trade relating to BOS components such as batteries and lamps. Compact fluorescent lamps used widely in systems are manufactured only in a handful of countries and exported everywhere. Sealed maintenance-free batteries, special low-maintenance batteries and nickel-cadmium batteries are also made in a limited number of countries. These items need large volumes to justify manufacture. Countries that do not have large domestic

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[14] W. Palz, "PV for the new century: status and prospects for PV in Europe", *Renewable Energy World*, vol. 3, No. 2, (2000), pp. 24-37.

[15] *PV News*, vol. 19, No. 2 (February 2000), and yearly February additions.

[16] G. E. Cohen, D. W. Kearney and G. J. Kolb, *Final Report on the Operation and Maintenance Improvement Programme for Concentrating Solar Power Plants*, Sandia National Laboratories (1999).

[17] W. Palz, "PV for the new century: status and prospects for PV in Europe", *Renewable Energy World*, vol. 3, No. 2 (2000), pp. 24-37.

markets have to rely on imports. As in the case of solar cells and modules, access to technology also determines the feasibility of local manufacture.

B. Solar thermal manufacturing

47. Manufacturing activity in the solar thermal sector can also be divided into three stages: (a) manufacture of the selectively coated absorber material, which requires relatively advanced technology and controlled conditions; (b) manufacture of the collectors which basically requires fabrication work; and (c) assembly of complete systems such as water heaters by adding a storage tank, supporting structures and piping. Here again, the first stage is carried out only in a few countries, with other countries importing the selectively coated material. Collectors can be and are being made by dozens of companies worldwide. In India also, there are over 40 companies that make collectors according to the national standard. System assembly is often a small enterprise- or dealer-level activity. Several hundred such companies are operating in many countries. The United States of America, Japan, Australia, Germany, Austria and Israel are among the leading manufacturing countries for solar collectors. There are no large companies as in the PV field. As a result, only a few companies are selling outside their region.

VI. Constraints on and barriers to solar energy utilization

48. The development and utilization of renewable energy technologies have faced numerous constraints and barriers during the past quarter-century. Some of the barriers have been reduced but others still remain to a significant extent. The barriers are of all types: technical, infrastructure, finance, human resources and awareness. Actions have been initiated both by Governments and by international agencies to mitigate them, but much more remains to be done.

A. Limitations imposed by resource characteristics

49. Solar energy is perceived as an intermittent energy source. This is not an insurmountable constraint, as proper design of systems and development of more efficient and economical storage systems can offer solutions. The diffuse nature of the energy source also means that large areas of land are required for large-scale power generation. Concentration technologies can help (and in any case are required for generation of high temperatures), but also may increase system cost. In urban areas, adequate space may not be available for water heating in large apartment buildings, hospitals or hotels, where there is also the problem of the availability of shadow-free space.

B. High capital cost

50. This is perhaps the biggest barrier to the large-scale use of solar and other renewable energy sources. It may be argued that the life-cycle cost of the energy from solar energy systems is lower compared with the cost of a conventional fuel-based system. However, the fact remains that the high initial cost is a major barrier. Innovative financing can help to mitigate this problem.

51. The user of a renewable energy system is also at a disadvantage compared with the user of a fossil fuel-based system. Unlike the latter who invests only in the device that uses the energy, the former must invest in the energy generator as well as the appliance. This problem is felt most acutely when one compares electrified villages with unelectrified ones, where the residents are asked to pay for the cost of electrification including the generation system. The inequality appears even more glaring considering the fact that people living in unelectrified areas generally have significantly lower incomes.

C. Insufficient awareness

52. The diffusion of renewable energy sources continues to be hampered by lack of awareness, both in industrialized and in developing countries. Even in a country such as Australia, "the public is not well informed as to how solar water heaters work".[18] Many consumers do not understand the difference between solar thermal collectors and PV panels. In many developing countries, most people are not aware of the type of applications that can be served by solar energy and also about the availability of various solar products. Continued promotional campaigns and demonstrations financed by Governments, manufacturers and non-governmental organizations are clearly required. In many countries, extension work relating to health care, agriculture and education is carried out through agencies and departments set up for this purpose. It is rare to find such a workforce for renewable energy. One of the options that could be considered would be to utilize the machinery of other extension services that exists; this, however, would require some training and awareness-raising among extension workers.

53. Inadequate attention to system design, manufacture, installation, operation and maintenance either individually or in combination can be the cause of systems' not working according to expectations or failing frequently. This situation led to a certain loss of credibility for renewable energy technologies. While such problems do arise with any new technology or industry, this problem, when coupled with the high initial cost and need to maintain a back-up, deters many potential users from investing in renewable energy systems.

D. Lack of manufacturing infrastructure

54. Lack of adequate local manufacturing capacity is a major barrier to wider-scale use of solar energy. While some countries might still choose to undertake only system integration, the diffusion of solar technologies can be rendered more effective if manufacturing capability in respect of PV modules and solar collectors is more widely developed. Thus, the development of requisite skills among small enterprises for carrying out proper assembly and installation is also an important consideration. The problems associated with access to technology, lack of capital, lack of trained personnel and relatively weak general infrastructure in many developing countries inhibit the establishment of local manufacturing capacity.

[18] *Report of the Photovoltaic Industry Roadmap Workshop* (Columbia, Maryland, Energetics, Inc., 1999).

E. Paucity of human resources and skills

55. The paucity of trained personnel can slow down field programmes and also lead to a host of problems ranging from faulty installation to poor maintenance, underutilization and total failure of systems. Failure of many solar thermal and PV systems can be traced to poor quality of plumbers and electricians. It is not enough to construct PV modules or solar collectors with a life of 20 years or more; it is equally important to have other reliable components, install the system correctly and maintain it properly. The general belief that solar energy systems require no maintenance is not correct; they require some minimum maintenance which can be provided only by personnel with the requisite skills.

56. There are numerous efforts in many countries to organize training programmes for renewable energy technicians. However, it is also noticed that most trained personnel cannot make a living entirely by repairing, say, solar systems. As long as the concentration of solar systems in a particular area is below a critical level, it remains difficult to retain trained manpower to service the systems. Manufacturers as well as other promotional agencies need to devise ways of overcoming this barrier.

F. Policy

57. A national policy framework that provides direct or indirect support for renewables is critical to their development. Lack of political will, inadequate awareness among decision makers, and economic factors have resulted in many countries' still lacking support mechanisms for renewable energy sources. The policy framework has to provide the financial or other incentives needed to level the playing field for renewables with respect to conventional energy sources.

VII. Economics of solar energy and prospects for future growth

A. Economics of photovoltaic systems

58. The number of applications for which PV is already "economic" is growing steadily and such applications account for about 70 per cent of global module shipments. The cost of PV power from stand-alone systems varies between US$ 0.30 and about US$ 0.80 per kWh, depending on the system configuration, location, type of battery and other parameters. This is roughly 6-10 times the price of conventional electricity in most countries. While this would be unacceptable in electrified regions, it can still be economic for isolated households and remote-area power. (Power from dry batteries can be 500 to 1,000 times as expensive as grid electricity, yet millions of batteries are used every year because they can be employed conveniently for small portable applications.)

59. Among the earliest applications that were considered economic were communications and signalling systems. Communication networks require reliable power on a variety of locations, many of them in forest or hilly areas. PV systems ranging from 500 W to 10 kW have been used the world over for providing power to microwave repeaters, cellular transmitters, radio and television broadcasting. Smaller power systems are being used in emergency call boxes, rural telephones and

other equipment. Over 150,000 systems were installed by the Indian Department of Telecommunications for providing wireless telephone connections in rural areas where grid supply was non-existent or unreliable. Each remote telephone unit is powered by a 70 W module. Such small power demands cannot be supplied economically by gasoline generators or other sources. PV power systems are also being used widely for off-grid uses such as recreation vehicles, boats and navigation equipment. Consumer items such as calculators and portable radios have long been powered by solar cells. Electric fencing in rural and forest areas is another application where the small power required is provided cost-effectively by PV.

60. There are two major applications where the economics of PV power are being studied closely: rural electrification and grid-connected power. The former is important in the context of providing electricity services to the estimated 2 billion people in developing countries living in unelectrified areas. Here, the economics of PV power has to take into account: (a) the cost of PV power either from a small power plant in a village or from a cluster of villages calculated on a life-cycle basis, taking into account also the cost of replacement of batteries and other equipment during the lifetime of the system; (b) the alternative cost of generating power from fossil fuels or large hydropower in a distant location; (c) the cost of laying a transmission line from the nearest point where the grid is already available; (d) the cost of installing a transformer and other equipment in the village to distribute the conventional power; and (e) the transmission and distribution power losses.

61. The above costs obviously vary from country to country and depend on the local geographical conditions. The competitiveness of PV systems also depends on the load in the village, which in turn depends on the number of households and the anticipated requirement in each household. In India, a comparative analysis that has taken into account all these factors shows that the PV option can be cheaper for a capacity of about 3 kW at distances beyond 3 kilometres (km) from the existing grid in hilly and forest regions, and beyond 6 km in the plains.

62. Grid-connected PV power is usually cheaper than power from stand-alone systems because storage is not necessary in grid-connected systems. Nevertheless, no PV power plant feeding power to the grid can at present compete with fossil fuel-based generation or even with other renewable energy systems based on wind or biomass. With power costs of about US$ 0.20/kWh and even higher ones for smaller rooftop systems, most such projects cannot be considered commercially. Practically, all large central power plants and rooftop systems are financed or subsidized through government programmes.

63. The key to lower costs for PV power is obviously the cost of PV modules. It is widely anticipated that the price of PV modules will come down to one third or one fourth of their present levels through large-volume production, automated plants and the introduction of new technologies. A number of studies and projections have been made regarding future costs. For example, a European Commission-sponsored study in 1996 projected that a 500 MW-per-year plant using the best available crystalline silicon technologies could produce modules at a cost of euro 0.91/W. However, a recent projection by Bayer Solar of Germany, a leading producer of silicon, indicates a module price of about US$ 2.50/W in the year 2010.[19] A study by Arthur D. Little Enterprises indicates that direct manufacturing costs could fall to US$

[19] H. D. Block and G. Wagner, 16th European Photovoltaic Solar Energy Conference, Glasgow (May 2000).

1.45/W for single crystal silicon and US$ 1.15/W for multi-crystalline silicon modules in the next 10 years.[20] This study also projects manufacturing costs of $1.40/W for amorphous silicon, $1.00/W for CIGS and $0.95/W for CdTe modules in the next 10 years. A recent study by Fraunhofer Management of Germany on thin-film photovoltaics indicates that PV systems in the 2.3 kW range based on thin-film technologies are not expected to become competitive with crystalline silicon-based systems until about 2008.[21] PV Energy Systems, a United States of America firm, projects PV module prices of about US$ 2/W based on crystalline silicon technologies and US$ 1.25/W based on thin-film technologies by the year 2010.[22]

64. In the past, such optimistic projections were also made and such projections have sustained many corporate PV programmes. However, some current projections appear to be more realistic. It appears feasible that thin-film modules will become available at prices ranging between US$ 1.25/W and US$ 1.50/W by the end of this decade. Besides the module prices, reductions are also expected in BOS and overall turnkey system costs. According to Japanese projections, the turnkey system cost could come down to 310 yen (¥)/W beyond 2005 with the cost of power ranging between ¥20 and ¥29/kWh.[23] This would still not be competitive with power generation from large fossil fuel plants. The era of solar PV power from large-scale grid-connected systems may arrive around 2020.

B. Economics of solar thermal systems

65. Low-temperature thermal systems for water heating have already achieved economic competitiveness in many countries. This explains the rapid growth in the installation of such solar water heaters for domestic purposes in Europe, the Middle East and Japan. Their economics are seen mainly in terms of savings in electricity bills. In Israel, compared with an electric heater, a solar water heater costing US$ 500 is estimated to result in a net saving of $58 per year.[24] In most parts of India, the cost of a domestic water heater is recovered in three years through reduction in the electricity bill.

66. The same, however, cannot be said in respect of industrial water heating systems where solar energy has to compete against coal, oil and gas. The payback times can stretch to five to six years which may or may not be attractive to commercial enterprises. Such systems are popular in countries that provide tax benefits and/or low-interest loans.

67. Solar thermal energy is generally not competitive for applications that can be powered by medium-grade heat such as cooling, water pumping and cooking. It is even less so for grid-connected power generation. Practically all solar thermal power plants built so far have relied on either tax benefits or direct government funding.

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[20] L. Frantzis and others, 16th European Photovoltaic Solar Energy Conference, Glasgow (May 2000).

[21] *NCPV Hotline* (22 February 2000).

[22] Paul Maycock, "Economic PV: a shift in thinking", *Renewable Energy World*, vol. 2, No. 5 (September 1999), pp. 73-76.

[23] International Energy Agency, *A Preliminary Analysis of Very Large-Scale Photovoltaic Power Generation Systems*, report IEA-PVPS VI-5 (1999).

[24] Joseph Nowarski, "Solar Israel: a practical and legislative model", *Renewable Energy World*, vol. 3, No. 2 (2000), pp. 92-99.

Commercially viable solar thermal power generation must await improvements in concentration technologies and large-scale production of components. The capital cost of parabolic trough plants are expected to fall from US$ 3,000/kW-US$ 3,500/kW in the near term to US$ 2,000/kW-US$ 2,500/kW in the long term.[25] Likewise, the capital cost of central receiver systems could come down to US$ 1,600/kW-US$ 1,900/kW in the long term. At that stage, the levelized energy cost could drop to US$ 0.05/kWh-US$ 0.06/kWh. There are hopes that this might become possible in the period 2010-2020.

C. Prospects for future growth

68. There are indications that current growth rates for PV and thermal systems will continue in the coming 10-20 years. The main reasons for this optimism are: (a) efforts by industrialized countries to meet their commitments on CO_2 reduction under the Kyoto Protocol[26] to the United Nations Framework Convention on Climate Change;[27] (b) improved economics in relation to conventional energy systems through technology development and large-volume production; (c) improvement in the reliability and performance of solar energy systems which may reduce attitude barriers; and (d) growing international recognition of the need to provide basic energy services to the nearly 2 billion people in developing countries who require them.

69. In the area of PV, United States of America industry has prepared a roadmap for growth.[28] According to different scenarios, based on different growth rates, worldwide annual PV module shipments could increase to between 1.5 gigowatts (GW) and 15 GW by 2020. Assuming a 25 per cent growth rate, cumulative worldwide shipments could rise from about 1,000 MW at present to about 85 GW. Such growth rates, however, appear unrealistic. If cumulative shipments were to double every four years on average, 32 GW would be reached by the year 2020. A number of actions would be required on the part of Governments and manufacturers to sustain even these growth rates.

70. In the area of solar thermal technology, the potential, at least in Organisation for Economic Cooperation and Development (OECD) countries, has been projected at between 0.5 m^2 and 1 m^2 of solar collectors per inhabitant.[29] The lower figure represents warmer climates and the higher figure is for the climates of northern and central Europe. Countries like Israel and Cyprus have already achieved this. On this basis, the ultimate potential in Europe would be about 200 million m^2.

71. Considering that no significant reductions in cost can be expected for solar water heaters, market growth will depend mainly on the relative cost of conventional energy. Assuming that about 1 billion people will use an average of 0.5 m^2 of solar collector area by 2020, the cumulative installation will reach 500 million m^2 by that

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[25] UNDP, Department of Economic and Social Affairs of the United Nations Secretariat and WEC, *World Energy Assessment* (forthcoming).

[26] FCCC/CP/1997/7/Add.1, decision 1/CP.3, annex.

[27] A/AC.237/18 (Part II)/Add.1 and Corr.1, annex I.

[28] *Report of the Photovoltaic Industry Roadmap Workshop* (Columbia, Maryland, Energetics, Inc., 1999).

[29] *Opportunities for Large-Scale Purchase of Active Solar Systems* (Harwell, United Kingdom, IEA CADDET Centre for Renewable Energy, December 1998).

time. These installations can contribute to savings in other forms of energy: oil, gas and coal.

72. There will also be a sizeable growth in solar thermal power generation. A generating capacity of 6,000 to 8,000 MW seems possible. On account of such growth in PV and thermal technologies, the overall contribution to world energy supply from solar energy could grow by a factor of 20-30 from the present level of about 0.02 per cent. This would lead to corresponding benefits from reduction in CO_2 emissions.

73. The above projections would appear to indicate that direct forms of solar energy will not make a significant contribution to the world energy supply during the next two decades. Some believe that solar energy can have an impact on the world energy scene only if an economic way is found to produce hydrogen from solar energy. Hydrogen is not a primary energy source but rather a versatile energy carrier that can be stored and transported. It can be used as a fuel for transportation — a major consumer of energy. It can also be used in engines for static motive power and for power generation. This aspect of solar energy utilization is not covered in this report because most work in this field is still experimental with no breakthroughs achieved so far. Moreover, much work still needs to be done on safe methods for handling hydrogen. Environment-driven policy measures could easily increase the contribution of solar energy in the world energy supply by a factor two to three times that projected for 2020 and even more in later decades.

VIII. Issues and approaches concerning the utilization of solar energy for rural areas

74. Energy for cooking is a major problem in rural areas, where the use of solar energy for cooking presents both opportunities and problems. Simple box-type cookers and small concentrators are not difficult to use. However, they suffer from problems of high initial cost and limitations in use. Box cookers take considerable time and cannot be used for frying. Dish-type cookers are faster but may require the user to stand in the sun. More sophisticated cooking systems would be even more costly. However, there are some advantages to solar cooking as well as substantial savings in conventional fuels that can be realized through large-scale use of solar cookers. The impact of solar cookers on rural energy is likely to be limited owing to their inherent constraints.

75. Lighting is another basic need in rural homes. Most unelectrified homes use kerosene or other oils for lighting. Hundreds of millions of lanterns in the world use these fuels. Studies have shown that electric lighting is not only far superior and safer, but also more economical compared with kerosene lighting.

76. Among the renewables, solar PV technology scores over other options, as it can offer small systems for each household separately (an option not available with the other technologies) or a "central" power plant in the village coupled to a small distribution system. Solar systems have no moving parts, are noiseless and require minimal maintenance. It is therefore not surprising that much of the discussion on decentralized rural electrification has focused around the solar PV option (the solar thermal option is not considered, as small power systems are still not mature).

77. Considering all aspects, it does appear feasible that solar energy can be used effectively to provide at least one form of energy — electricity — to the rural areas of the world. The impact of large-scale programmes can, however, be significant in terms of the number of people who benefit and the contribution that solar energy can make to improvements in the standard of living of people in some of the most impoverished regions of the world. Concomitant benefits include improved health care, education, communications, and access to information.

78. The above discussion covers only the minimum needs that can be met from solar electricity. There are other requirements in rural areas that also need to be addressed including water pumping for drinking water and agriculture, water treatment, drying of agricultural produce and refrigeration. Water pumping has long been a major PV application. Large-scale use of PV systems for water pumping may be feasible only if the module costs come down by a factor of two to three. This may happen within a decade. Solar drying has a role in localized situations, but the necessity of having different dryer designs and sizes for different crops as well as the seasonal utilization of these systems is an obstacle to their large-scale use. Refrigeration is again confined to applications such as vaccine preservation which cannot always be evaluated on the basis of economic criteria.

IX. Policies and actions for wider use of solar energy

Policies and enabling environment

79. The need for Governments to establish clear policies for energy for sustainable development, including the promotion of renewable energy technologies, has been highlighted in the past. Governments could take steps ranging from a national energy policy statement to legislative measures and the introduction of an appropriate fiscal regime. If a clear niche was identified for the use of solar energy and other renewable energy sources in the national energy mix, it would help mobilize investments and focus national efforts. This has to be supplemented by the establishment or identification of appropriate institutions and implementation of supporting measures relating to human resources, commercialization and general rural development.

Financial incentives

80. Direct capital subsidies are often not favoured as a long-term strategy to promote renewable energy. The contention is that such subsidies are not sustainable in the long run and ultimately hamper market growth. Therefore, phasing out subsidies for both conventional and renewable energy is an option to be considered seriously. In the short term, some form of subsidy for the poor appears to be necessary for the growth of renewable energy markets. Other forms of incentives include tax credits, exemptions from duties and preferential pricing for electricity from renewable energy sources. These are being applied in various ways in many countries. The most recent development is the German Renewable Energy Law of 2000 which allows a price as high as deutsche mark (DM) 0.99 for electricity from PV.

Economic and legislative measures

81. Legislative measures can achieve certain goals that are in the public interest even if they are justified purely on financial grounds. As a move towards sustainable development, countries could consider enacting laws that would, for instance, require all new buildings to incorporate energy-efficient features and install solar water heaters if hot water is necessary in the buildings. Appropriate laws relating to emission controls from diesel or gasoline generators encourage greater use of PV systems. Other laws could even require utilities to generate a certain minimum percentage of power from renewables and industries to meet a part of their energy requirements from these sources. Economic measure can also provide for easy financing for renewable energy projects and manufacturing activities.

Intensification of R&D

82. The slowing down of the research effort during the 1980s has perhaps delayed some promising technologies in reaching maturity. There is general concern that, even now, R&D in support of sustainable energy development is not adequate. This will require a commitment on the part of Governments and large companies to deploy financial and manpower resources for accelerating research efforts. Among areas that need to be studied further are materials, designs, component development, system aspects and manufacturing technologies. There is a need to enhance the current level of research funding by a factor of two to three during the next five years. The benefits of such acceleration will be seen in the decade that follows.

Technology diffusion and transfer

83. The wider use of available technologies requires the diffusion of technologies on a global scale and establishment of local manufacturing facilities. The need is particularly great for developing countries that do not have adequate intrinsic technological strength. The training of manpower is an essential prerequisite. The undertaking of a large number of demonstration and pilot projects in developing countries is another way to promote diffusion of solar technologies. There is scope for considerable international cooperation in this aspect.

Commercialization and entrepreneur development

84. Large multinational corporations alone cannot reach out to all parts of the world and supply products. Entrepreneurs are needed not only to act as dealers but also to undertake local assembly and manufacture. This also promotes employment and can be viewed as an indirect benefit of decentralized energy development. Those who are able to establish energy service companies and operate small power plants for local people form an important class of entrepreneurs. If they were offered financial assistance to install and manage such systems, individual households would not need to invest in the generation component of solar energy systems, and solar energy would become more affordable to millions of people.

Financing

85. The financing needs mentioned above will have to be effectively met by existing financial institutions or by establishing new institutions. A change in the mindset of banks and financiers will be necessary to promote lending for renewable projects. Equally important is the need to establish retail financing networks or

microcredit arrangements. Despite a few good examples, more needs to be done in this area.

International cooperation

86. There is significant scope for international cooperation in achieving many of the objectives mentioned above. What is needed first of all is a clear assignment of priorities by donor countries and international organizations to sustainable energy programmes. From this will flow projects that can support training, capacity-building, awareness-promotion and actual utilization activities. However, not all activities involve a donor-recipient relationship. There is already a good measure of cooperation among the International Energy Agency (IEA) and EU member countries. This needs to be strengthened and the benefits also made available to developing countries. Technical cooperation among developing countries is another concept that has been mentioned often in international forums but has received scant financial support. The value of such cooperation in the renewable energy sector can be very high. Some of the international funding in this sector should be earmarked for technical cooperation among developing countries.

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Technical cooperation activities of the United Nations system in the field of water resources

Report of the Secretary-General

Summary

The present report provides information on the technical cooperation activities of many of the agencies in the United Nations system in the field of water resources undertaken since 1998. It also provides reference to the analytical and normative activities of the United Nations system in water resources development and management. The report touches on the evolution of technical cooperation in water resources over the past decade, which has enabled United Nations agencies to act in a support role to Governments. The United Nations technical assistance is concentrated to the area of capacity-building.

The report provides details of assistance provided by a number of United Nations organizations in support of socio-economic development in such areas as integrated water resources management, water supply and sanitation, water for sustainable urban development and the mitigation of water-related natural disasters. Since integrated water resources management is intertwined with the protection of aquatic ecosystems, information management, capacity-building and financing, information is also provided on programmes to support Governments in their efforts to protect and manage their water resources through the protection of water quality and ecosystems, information management, capacity-building and financing. The report concludes with some lessons learned by the United Nations agencies over the years.

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I. Introduction

1. In its decision 1999/277, the Economic and Social Council adopted the provisional agenda and documentation for the second session of the Committee on Energy and Natural Resources for Development. Item 5 of the Committee's agenda concerns the strengthening of and coordination of the activities of the United Nations system in the field of water resources, and a report of the Secretary-General on technical cooperation activities in the field of water resources development has been mandated under that item. The preparation of the report was entrusted to the Department of Economic and Social Affairs, in its capacity as secretariat of the ACC Subcommittee on Water Resources.

2. The main activities of United Nations entities in the field of water resources are: (a) data gathering/analysis and preparation of studies and reports; (b) organization and servicing of meetings and workshops; and (c) technical cooperation, including advisory services and field projects. The present report will concentrate on activities under item (c).

3. The present report provides information on the technical cooperation activities of many of the agencies in the United Nations system in the field of water resources undertaken since 1998. The report of the Secretary-General on activities of the organizations of the United Nations system in the field of freshwater resources (E/C.17/1998/3) covers technical cooperation activities, as well as analytical and normative activities under items (a) and (b) above. The present report updates the information on technical cooperation of some agencies, with brief reference to the analytical and normative activities of the United Nations system in water resources development and management.

4. There has been considerable evolution of technical cooperation during the past decade. In the early 1990s, the United Nations Development Programme (UNDP) made a serious effort to shift project execution from United Nations agencies to national agencies. United Nations agencies now play more of a support role, providing technical advisory services, building technical capacity and strengthening institutions in water resources, at the request of Governments. The value of the United Nations agencies has been in helping to define global and regional agendas and assisting Governments in formulating policies and strategies in water resources management. In recent years, better integration of their own analytical, normative and technical cooperation activities has enabled most of the agencies of the United Nations system to provide a better supportive response to countries concerned with implementing the commitments of major United Nations conferences, such as the International Conference on Water and the Environment (Dublin, January 1992) and the United Nations Conference on Environment and Development (Rio de Janeiro, June 1992). As a result of the decline in project funding from UNDP, many United Nations agencies have begun to seek financial support from other sources, in particular bilateral donors. This has changed the level and form of cooperation within the United Nations system and in some cases has resulted in competition for the same sources of bilateral funds.

II. Activities of the ACC Subcommittee on Water Resources

5. The ACC Subcommittee on Water Resources is composed of over 20 entities of the United Nations system involved in the field of freshwater resources. The Department of Economic and Social Affairs of the United Nations Secretariat serves as the secretariat for the Subcommittee and provides substantive servicing of its annual sessions. The Subcommittee reports to ACC through the Inter-Agency Committee on Sustainable Development (IACSD). As approved by IACSD in June 1994, among its main functions the Subcommittee has to enhance coordination among the entities of the United Nations system in the field of water resources; to assist in the preparation of reports for the Commission on Sustainable Development, the Committee on Energy and Natural Resources for Development, the Economic and Social Council, the General Assembly and other intergovernmental bodies; to formulate common strategies and joint programmes among the organizations of the United Nations system; and to provide a mechanism for a dialogue with international, regional and bilateral organizations, as well as with active non-governmental scientific and professional organizations.

6. The Subcommittee has also been mandated to monitor and review progress in the implementation of the Mar del Plata Action Plan and chapter 18 of Agenda 21. In that regard, at its fourteenth session, the ACC Subcommittee agreed that the Department of Economic and Social Affairs would act as a focal point

for integrated water resources development and management; the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the World Meteorological Organization (WMO) for water resources assessment; the World Health Organization (WHO) for protection of water resources, water quality and aquatic ecosystems and for drinking-water supply and sanitation; the United Nations Centre for Human Settlements (Habitat) for water and sustainable urban development; the Food and Agriculture Organization of the United Nations (FAO) for water for sustainable food production and rural development; and WMO for impacts of climate change on water resources. With regard to cross-cutting issues, it was agreed that the International Research and Training Institute for the Advancement of Women (INSTRAW), the United Nations Children's Fund (UNICEF) and UNESCO would act as focal points for women's communication, education and research, respectively. Major recent outputs of the Subcommittee include the publication of various regional water resources assessments in 1991 in connection with the implementation of the Mar del Plata Action Plan; the organization of the 1992 International Conference on Water and the Environment (Dublin); the publication of the *Comprehensive Assessment of the Freshwater Resources of the World* in 1997; the organization of an expert group meeting on strategic approaches to freshwater management, held in Harare 1998, in preparation for the sixth meeting of the Commission on Sustainable Development; and the recent preparatory process of the forthcoming *World Water Development Report*.

7. The ACC Subcommittee met in March 2000 in a special session held at The Hague. It agreed that greater efforts should be made to seek additional resources from donors, particularly for concrete activities, such as the preparation of the forthcoming biennial *World Water Development Report*. The Subcommittee agreed that efforts would be made to monitor national and international implementation (as opposed to compliance), not only through the *World Water Development Report* but also through other activities related to the review of chapter 18 of Agenda 21. The Subcommittee also agreed to look into the relationship between freshwater and gender.

8. Collaboration of the members of the Subcommittee with potential donors has actually recently occurred in the case of initiatives in the areas of arsenic contamination of drinking water sources and the preparation of the initial groundwork for the *World Water Development Report*.

III. Technical cooperation activities of the United Nations system in the field of water resources

9. The magnitude of the involvement of organizations of the United Nations system in the field of water resources can be appreciated from the expenditures on technical cooperation activities of the main funds and programmes. UNDP finances technical cooperation activities in integrated water resources development and management in all developing country regions; it is currently funding 168 water resources projects in 67 developing countries and those with economies in transition, for a total amount of US$ 335 million. The World Bank also provides loans and technical assistance to many ongoing projects in water resources development, capacity-building and management in many developing countries. For the years 1998 and 1999, the World Bank had made funding commitments of $4,300 million for 66 projects, over 40 per cent of which went to the East Asia and Pacific region. Two thirds of the World Bank's funding for water resources projects was in the area of institutional development and environment. Another 22 per cent was concentrated in the urban water supply and sanitation area. In addition, the grants and concessional funds disbursed by the Global Environmental Facility (GEF) from 1992-2000 in the international waters focal area provided $399 million in grants for 47 water-related projects. This was accompanied by another $419 million in co-finance from other sources.

10. UNICEF has historically played a leading role in providing water supply and sanitation and in supporting the capacity-building of Governments and communities in over 100 countries in its efforts to increase access to safe drinking water and environmental sanitation. In 1999, UNICEF expenditure for water supply, environment, sanitation and hygiene education programmes amounted to an estimated $70 million. The UNICEF-supported country programmes helped an estimated 9 million people gain access to improved water and helped an estimated 5 million people to sanitation facilities in 1999. Over the 1990-1999 period, UNICEF investments in water

supply, environment, sanitation and hygiene education amounted to some $952 million, including nearly $250 million for emergency interventions.

A. Integrated water resources development and management

1. Support for national integrated water resources strategies

11. The Department of Economic and Social Affairs has been involved for many years in developing strategies for integrated water resources development and management in the context of the implementation of Agenda 21. The Department promotes integrated water resources planning and management, using the natural water basin as a reference unit. An essential element of its approach is to consider socio-economic and hydro-environmental systems as mutually dependent and to understand the interrelationships between them. Environmental protection and equitable allocation of often limited and vulnerable water resources suffer from a lack of integrated and dynamic planning and management. Governments need to play a leading role in preserving water for future generations, and stakeholders need to be closely associated in planning and implementation stages. An expert group meeting on strategic approaches to freshwater management considered and made recommendations on four cross-cutting issues for integrated water resources management: water as the key resource in sustainable development; freshwater ecosystems and water quality; economic and financial issues; and participation and institutions for integrated water resources management.

12. Participatory planning and management of water resources, based on sound information and decision-aid tools, are essential to avoid conflicts, to properly allocate and make efficient use of resources and to solve complex environmental problems. Capacity-building and exchange of experiences are required to help economies rapidly achieve sustainable growth, to maintain aquatic ecosystems and to resolve conflicting demands on limited water resources.

13. The cross-sectoral and multidisciplinary approach takes into account competitive water resources uses for rural and urban water supply and sanitation, irrigation, industry, recreation, hydropower, navigation, fishing and for sustaining aquatic ecosystems, and is based on diagnostic studies and on an interactive dialogue among stakeholders. That approach allows national authorities to define policies and strategies for integrated water resources management.

14. The Department is providing technical support to many nationally led water management programmes. For example, in Ethiopia assistance is being provided for the preparation of the Government's water sector development programme. The federal water policy and national water code have been developed by the Government, and reflect strong political commitment to improve the overall management of water resources in Ethiopia. The Government has formally established an inter-sectoral committee composed of senior level officials and chaired by the Minister of Water Resources. As this is a participatory process, the involvement of NGOs, donors and the regional water bureaux are essential. The Department is also assisting in many other water management initiatives. For example, in the Syrian Arab Republic, assistance has been provided to conduct a comprehensive analysis of the water sector in order to support national experts and authorities to identify priorities and set recommendations for an integrated water resources management programme, based on sustainable development principles. Proposed components for strengthening institutional and technical capacities include local pilot demonstration projects (in irrigation management, urban water supply management and controlling/mitigating industrial pollution); basin-level water management; strategic planning and institutional coordination; and human resources development. The Department is providing similar technical advisory services on these types of sustainable development approaches to Chad, Côte d'Ivoire, Madagascar, the Niger, and Yemen.

15. The Economic and Social Commission for Asia and the Pacific (ESCAP) carried out a survey of existing water allocation policies and regulations in all the countries of the region in 1999. The project, entitled "Optimum water resources allocation among water-use sectors for sustainable socio-economic development", was funded by the Government of the Republic of Korea. A regional workshop on the allocation of water resources among water-use sectors was held in Bangkok in February 2000 to exchange information and experience on the principles and policies of water allocation and to review and adopt the draft water allocation policies and strategies for use by

the countries. A publication on this subject is being prepared for wide dissemination.

16. Moreover, a joint FAO/ESCAP regional project on consolidating experiences in the region from the World Water Vision consultation process was formulated in late 1999 and its pilot phase is currently being implemented by ESCAP, with financial resources provided by FAO. The pilot phase includes case studies and round-table workshops of experts to discuss priority programmes of action for successful implementation of the respective national water visions, including water for food and rural development, in four selected countries: Malaysia, the Philippines, Thailand and Viet Nam. The pilot phase is scheduled to be completed by the end of June 2000.

2. Protection of water resources, water quality and aquatic ecosystems

17. Actions are also needed to protect the health and productivity of the aquatic environment, and impacts on human health resulting from degraded water resources. There are economic, social and environmental consequences from the degradation of freshwater resources and aquatic ecosystems. These include impacts on food production and human health. Efforts to design and implement strategic approaches and plans for urban and rural sanitation and for wastewater treatment at the pollution source need support in developing countries and countries in transition.

18. A project of the Department of Economic and Social Affairs in Estonia concentrates on hazardous substances in freshwater and in the coastal marine waters. This project is assisting the Government of Estonia to formulate a three-year programme for collecting basic information in order to take decisive actions to remediate polluted surface and groundwater resources of the country, including land-based pollution of coastal areas. The programme is designed to address three interdependent problems: (a) lack of systematic knowledge on the extent, magnitude and sources of water contamination by hazardous substances in Estonia and its coastal zones; (b) insufficient institutional capacity at national and local levels — design and implement remediation strategies; and (c) inadequate public awareness of hazardous substances in the aquatic environment. The programme gives special importance to groundwater resources, as they are widely used for domestic water supply.

19. WHO, FAO and the United Nations Environment Programme (UNEP) have collaborated in the joint Panel of Experts on Environmental Management for Vector Control (PEEM) since 1981. Habitat joined the group in 1991. While the Panel of Experts itself is currently suspended, certain activities are still carried out under the interim arrangements.

20. An area of increasing interest in the WHO/FAO/UNEP collaboration is that of alternatives to the use of dichlorodiphenyltrichloroethane (DDT) for malaria vector control, against the backdrop of the ongoing intergovernmental negotiations on persistent organic pollutants (POPs). A UNEP guidance document on alternatives to POP pesticides, under preparation with inputs from FAO (integrated pest management) and WHO (vector control), will address environmental management measures, in particular in water resources development.

21. Health impact assessments have been a key theme in the work of PEEM. Such assessments aim to reduce the adverse health effects of development, including water resources development, through a methodology that covers the identification of vulnerable groups and of health hazards in a specific project; the definition of environmental and institutional risks; and the development of mitigating measures that can be incorporated in the design, construction or operation of the project. Implementation of health impact assessment procedures critically depends on an enabling policy framework at the national level.

22. In recent years, PEEM has organized national seminars on the review and adjustment of water resources development and management policies to incorporate health considerations (Benin, 1993; Zambia, 1996; Malawi, 1998; Ecuador, 1999). Reports are available from the PEEM secretariat, located at WHO headquarters in Geneva.

23. Inter-agency collaboration under PEEM also focuses on setting the agenda for multidisciplinary research on environmental management measures for health promotion and protection in water resources development projects. It also identifies partner institutions, assists in resource mobilization and coordinates scientific backstopping as research is carried out. Support is being provided by PEEM to a consortium of research institutions in Denmark and the Philippines on a research proposal on environmental

management for irrigated rice production areas in the Philippines to control schistosomiasis transmission.

24. Two relevant publications initiated by WHO/FAO/UNEP/Habitat/PEEM are: *Water Resources: Health, Environment and Development* (1999) *and Dams and Disease: Ecological design and health impacts of large dams, canals and irrigation schemes* (1999), which, among other things, reflects PEEM's involvement in the health issues of dams built on the Senegal river basin.

3. Information management

25. Adequate collection, storage, processing and presentation of information are a critical component of integrated water resources management. Strategic approaches to information management for integrated water resources management need specific support. Given existing financial constraints in many countries, the optimum information requirements for effective integrated water management planning at the local, basin, national and international levels need to be defined with a view to maximizing the value of the information gathered.

26. Required changes in information management and dissemination to enable a country to integrate hydro-environmental and socio-economic data need also to be established and supported, as well as methods of rationalizing and enhancing data monitoring networks, data archiving. Technical capacity needs to be strengthened in order to make medium to long-term predictions of water availability and use and resource balances. New information technologies can be used inside countries and between countries, as a tool to exchange information on good practices and develop regional cooperation.

Water resources assessment

27. Assessment of surface water and groundwater are systematically included in all technical cooperation programmes supported by the Department of Economic and Social Affairs for water resources management. This is being done in, for example, Yemen and Madagascar.

28. Technical cooperation activities of the International Atomic Energy Agency (IAEA) cover isotope applications in a broad spectrum of fields, involving hydrogeological investigations of groundwater occurrence, subsurface flow, transport dynamics and hydraulic interactions; applications in geothermal systems; surface waters; local scale hydro-engineering applications (including sediment transport dynamics in rivers and estuaries, sedimentation in lakes and reservoirs, study of leakage losses from hydraulic structures); and analytical work related to isotope hydrology.

29. While the Agency's subprogramme on water resources involves continued research and development efforts for improving and refining isotope methodologies, as well as dissemination of information in that specific field, the technical cooperation programme provides the main avenue for wide applications in member countries. The effort in recent years to extend the use of isotope hydrology for water resources development and management has resulted in a considerable increase of support to technical cooperation projects — there are currently 160 projects in 63 countries, with total budgetary allocations of US$ 20 million over the last 10 years.

30. For the 1999-2000 cycle, 28 national and six regional new technical cooperation projects were included in the field of isotope hydrology. This involved 48 member States and a total budgetary allocation of US$ 6.7 million. Together with the ongoing projects from the earlier cycle, a total of 55 technical cooperation projects are being implemented during the 1999-2000 cycle.

Water Resources Learning Network

31. The Department of Economic and Social Affairs has recently received Development Account funding to establish a network of distance learning centres for training in water resources development and management, initially in Africa. The objective of the project is to develop national capacities that will promote the development and implementation of national water strategies in developing countries, at the local and basin levels. The promotion of integrated water resources development and management, in practice, will be carried out through: (a) a network of national capacities; and (b) a water virtual learning centre geared towards building national capacities and focused on water supply in underserved areas (rural and peri-urban) and on management of shared river basins.

Software for water resources management

32. In the Niger, an integrated water information system has been developed by a team of national and international experts for the Ministries of Water Resources and of Environment. The system is within the framework of a UNDP-financed Department of Economic and Social Affairs project, entitled "Planning, development and management of groundwater resources of the Republic of Niger". The system has been developed as the main support to prepare the first water master plan of the country and is used to monitor the implementation of the plan to respond rapidly to variations in planning scenarios and natural hydro-systems.

33. Similar systems have been developed in Mali, Senegal, and the Central African Republic. Comprehensive information systems are being developed in Yemen and in Madagascar. All systems are tailor-made to respond to country characteristics and needs in terms of systems on which national staff has been trained and software being used in the country. The common features of these systems are that they are integrated, can work at different scales and are easily adaptable by national staff trained to that end.

4. Capacity-building to enhance participatory approaches and improve institutional and regulatory frameworks

34. The Department of Economic and Social Affairs, working with Governments and UNDP, has implemented technical cooperation projects aimed at building national capacities that incorporate principles of sustainable development, centred on people. These projects aim at integrated water resources development and management, within national policies, strategies and programmes for water resources development. These coordinated initiatives are being carried out in a number of developing countries and regions, with the support of the Department, including Yemen, Zimbabwe and many other countries of Africa and Western Asia.

35. In Yemen, the Department has implemented a programme on sustainable water resources management over the past four years, with a total budget of almost $14 million. This programme aims at capacity-building for integrated water resources management, in support of the Government's effort to create an independent national water resources authority to regulate and control the use of its water resources, seriously depleted by overexploitation and anarchic development. The authority is now the main body for policy-making, planning and the management of water resources. It also provides advice as a donor coordinator for the water sector. Its main focus is on: the development of legal and institutional frameworks; water resources assessment, monitoring and control; demand management and public awareness; the decentralization of management responsibilities to regional and local levels; and the preparation of all relevant documentation for decision makers and users. Capacity-building is achieved through the implementation of 13 regional management plans for the efficient use of water resources, in areas facing acute water problems. The experience gained in these efforts will then be used in formulating sound national water resources management policy and implementing strategies and in continuing the planning process for the remaining nine regions.

36. A project of the Department of Economic and Social Affairs in Zimbabwe aims at capacity-building for sustainable water resources management. The Government of Zimbabwe has undertaken major reforms in the management of its national and international water resources, and capacity-building is needed at all levels to ensure an effective implementation of its water resources management strategy. This project aims to build full managerial and technical capacities of the newly formed Zimbabwe national water authority and to ensure sustainable development and management of Zimbabwe's water resources. It includes strengthening technical capacities for policy development, and for operation and maintenance of the national hydro-meteorological monitoring network. Support for effective stakeholder participation and institutions for integrated water resources management is necessary to achieve the goal of sustainable water management.

37. The Department also provides technical support to similar capacity-building projects aimed at enhancing participatory approaches in Chad, the Syrian Arab Republic, Ethiopia and the Niger basin. In Chad, the Department has assisted the Government, under the authority of the Prime Minister, to establish a mechanism composed of a multisectoral technical committee and a national committee for water management, representing 10 ministries and four representatives of users and elected people. Those two

committees are reporting to the existing national commission for the environment. All major projects, and strategic decisions, related to water resources, are progressively to be reviewed by those committees.

38. In the Syrian Arab Republic, the Department is promoting and defining, through three local demonstration projects, efficient and safe water management in irrigation, industrial pollution control, and urban water supply, a mechanism linking those local experiences with the regional/basin and the central/cross-sectoral levels.

39. In Ethiopia, the Department is supporting a one-year consultative process between local actors and eight regional technical committees, and between the committees and those responsible for the preparation of the water sector development programme. The exercise will be guided through regional meetings involving representatives from the central level, from regional authorities and experts from various sectoral groups, including water planning, agriculture and health. Relevant actors from the private sector will be invited to participate.

40. In the Niger river basin, the Government of Mali and the Niger basin authority hosted, with the support of UNDP and DESA, a meeting on the theme "Holistic and sustainable management of Niger basin resources". Representatives of eight riparian countries of the Niger river basin (Benin, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, the Niger and Nigeria) attended, as well as regional and international organizations, multilateral and bilateral donors, users, professional associations and NGOs. Interactions between development and environment were discussed, as well as ways and means to promote people-centred sustainable development in practice throughout the basin, including a participatory approach and institutional reforms at regional level.

41. Under the PEEM activities referred to above, WHO/FAO/UNEP, with their collaborating centres, the Danish Bilharziasis Laboratory and the Liverpool School of Tropical Medicine, have developed and tested a training course entitled "Health opportunities in water resources development", which aims to develop the skills of middle-level managers, working in different agencies, to participate effectively in the intersectoral development dialogue, and to ensure that environment and health issues are addressed in a timely manner, resulting in improved sustainability of water projects. The course was held in Zimbabwe, Ghana, the United Republic of Tanzania, Honduras and India, and reports are available from the PEEM secretariat. Capacity-building using that course is being extended to regional institutions in sub-Saharan Africa, through the Eastern and Southern Africa Management Institute, in order to offer the course in its permanent training programme.

42. ESCAP and the Netherlands technical cooperation programme have organized training courses on thematic maps in geology for urban planning and on geographic information systems in geology for urban planning. These training courses were attended by geo-scientists and planners, and highlighted the pertinent geo-information that needs to be communicated to decision makers. At the same time, techniques and methodologies to organize and present relevant geo-data in a user-friendly format have been shared at such training events. The training courses were held in 1998 and 1999, and served to bring participants up to date on the latest developments and to make them aware of the urgent need for close collaboration between the earth science and planning communities.

43. A capacity-building project executed by ESCAP and funded by the Development Account focuses on strategic planning and management of natural resources development (including water resources) and environmental protection in developing countries in the Asia and Pacific region. The project, to be implemented from 2000 to 2004, is expected to produce the following outputs: guidelines on strategic planning and management of natural resources development and environmental protection, including 10 country studies; five regional workshops, for the five subregions of ESCAP, to train a core group of about 100 experts for the networks; and 15 national workshops to train about 300 persons in the application and implementation of the guidelines.

5. Financing of water resources development and utilization

44. Given its crucial importance to sustainable water resources development and management, the mobilization of financial resources at the local, national, regional and international levels must be a top priority. Efforts to generate and utilize financial resources efficiently need specific support and promotion of good practices. These include action

proposals for Governments and the international community on water-pricing policies and appropriate cost-recovery schemes that would better reconcile equity and efficiency goals; specific proposals on how public and private actors could be both regulated and engaged in the cost-recovery effort; and the identification of priorities and strategies at the local, national and international levels, for the generation and efficient use of financial resources.

45. Issues where political commitment at different levels would make a difference include service-pricing policies, tax redistribution and cost-recovery schemes that better reconcile equity and efficiency aspect; proposals on how to enable and regulate the role of civil society, municipalities, public and private actors in demand-led water operations and finance; and the generation of additional national financial resources to promote rural water supply and urban sanitation. The technical support of the Department of Economic and Social Affairs has been provided to define, plan or implement such efforts in Madagascar, the Niger and Mauritania.

46. An illustrative example of local mobilization of financial resources combined with private-sector involvement is provided by a technical cooperation project designed and assisted by the Department in a remote area of Mauritania (the Hodhs). Until recently, drinking water was supplied by unsustainable and poorly maintained hand pumps installed years ago in 90 villages. Maintenance was supposed to be provided by the administration in the capital, Nouakchott, but there was access neither to spare parts nor to repair persons. At the end of the technical cooperation project, more than 90 per cent of the villages were autonomously funding the maintenance of their pumps, with trained help from the local private sector (repair persons, spare parts traders, etc.) and supervision by local and national authorities in charge of water resources.

B. Drinking water supply and sanitation

47. Mandated to assist countries in fulfilling the basic needs of children, including the supply of safe water and sanitation, UNICEF has a large portfolio of water and environmental sanitation and hygiene education projects. These are currently carried out in some 81 countries through regional and field offices and in cooperation with multilateral agencies, Governments and non-governmental organizations. Most water, environment, sanitation and hygiene education programmes and resources are concentrated in Africa, South Asia, and Latin America and the Caribbean. UNICEF country programmes focus both on advocacy for strategic changes in sectoral policy and on programme implementation with both Governments and large sectoral agencies. In the context of child and human rights, many UNICEF country water and environmental sanitation programmes emphasize improved access for marginalized communities.

48. Within the framework of its water and environmental sanitation strategies (approved in 1995), the shift in UNICEF water and environmental sanitation programming towards an increased focus on environmental sanitation, hygiene education and behavioural change continues to gain ground at the country level. In 1999, more than 50 UNICEF offices were involved in hygiene promotion. Within the context of the child-friendly school initiative and to increase the enrolment of girls and reduce drop-out rates, more than 35 countries were managing school sanitation and hygiene programmes in 1999, almost double the number in 1997. To improve the quality, the advocacy potential, and the real involvement of education and community stakeholders in these programmes, UNICEF has launched a two-year pilot project (2000-2001) to test and disseminate successful methodologies and lessons learned in this important new area.

49. UNICEF has entered into formal partnerships with several other United Nations organizations in the hope of increasing national, regional and global cooperation. For example, the WHO/UNICEF joint monitoring programme on water and sanitation was launched in 1990; the WHO-UNICEF joint strategy on water supply and sanitation was approved by the WHO-UNICEF Joint Committee on Health Policy in May 1997; and a collaborative agreement with the World Bank on water supply and sanitation in Africa was recently signed.

50. Collaboration within and outside the United Nations system has always been key to UNICEF programme implementation. For example, in the UNICEF-supported Guinea worm eradication programme in Africa and Asia, UNICEF works in close partnership with such institutions as: Global 2000 of the Carter Center, WHO, the United States Peace Corps and the Centers for Disease Control, as well as with

several donors, such as the Norwegian International Development Agency, the Canadian International Development Agency, the United States Agency for International Development and NGOs.

51. In the context of exploring new partnerships, UNICEF and the Worldwide Fund for Nature launched a study on freshwater for India's children and nature, which was the starting point for a more extensive cooperation at national and regional levels to promote community management of water resources and to establish the fundamental importance of overall ecosystem conservation.

52. The Department of Economic and Social Affairs also carries out technical cooperation projects in the field of rural water supply and of national sanitation programmes. For example, in Morocco the Department, in cooperation with other organizations, is executing projects on rural water supply, national strategy and master plan for urban sanitation.

C. Water for sustainable urban development

53. Within the context of its geology for urban planning programme, ESCAP periodically convenes the Forum on Urban Geology in Asia and the Pacific to discuss, *inter alia*, the adverse impact of groundwater overexploitation in mega-cities of the region, on land subsidence and recurrent flooding. The aim is to improve coordination among local government departments dealing with surface and groundwater resources, and to provide effective inputs from geo-science institutions in the land-use/urban planning process.

54. With funding from the Netherlands, ESCAP hosted the fourth session of the Forum early in 1999 and reiterated the need to guard more closely underground freshwater resources from pollution due to ill-informed solid waste disposal at unsuitable sites. These and other problems affecting groundwater resources as well as urban flooding and relevant countermeasures were described in two publications, both issued in 1999: *Urban Geology in Asia and the Pacific*, volume 10, and *Urban Geology of Dhaka, Bangladesh*, volume 11.

55. Advisory missions were fielded to urban areas in the Islamic Republic of Iran, Pakistan, Kazakhstan and the Lao People's Democratic Republic to help identify common problems and solutions, and to stimulate the creation of semi-permanent urban geology units with the explicit task of advising local authorities on how to avoid the above-mentioned adverse effects of ignoring natural (hydro) geological conditions in fast-growing Asian cities.

D. Water for sustainable food production and rural development

56. According to the most recent FAO estimates, agriculture accounts for 70 per cent of all water use (85 to 95 per cent in developing countries). Irrigation represents less than 20 per cent of cultivated land but contributes 40 per cent to overall food production.

57. Conditions of physical water scarcity exist in the Near East, North Africa, East Asia, Northern China and parts of Latin America, while economic/financial water scarcity is prevalent in sub-Saharan Africa and in other developing countries of Latin America and Asia.

58. Under these circumstances, there are two main issues for FAO: (a) water conservation in agriculture (more crop per drop) requires a significant improvement of local water management and the mitigation of adverse effects of irrigation (waterlogging and salinity); and (b) because of intensifying intersectoral competition for raw water, water resources management has to be integrated across natural units, economic sectors and administrative jurisdictions. This integration requires multidisciplinary implementation, with strong partner organizations to assist in the monitoring of implementation, the financing of investments and the fundamental operational research to improve the performance of irrigated agriculture.

E. Water-related disasters, including floods and droughts

59. The relationship between water and natural or man-made disasters should be fully taken into account within national development strategies as an integral component of disaster prevention and mitigation plans. This relationship can be seen from two perspectives: the occurrence of water-related disasters caused by hydro-meteorological extremes, such as droughts and floods, and the destruction of infrastructure and contamination of water sources by earthquakes,

volcanic activity, tidal waves, land and mud slides, among others, and also by disasters of a technological nature. The failure to limit environmental degradation resulting from human intervention increases the vulnerability of risks posed by water-related natural disasters. Major technological and other disasters with an adverse impact on the environment can be a substantial obstacle to attaining the goals of sustainable development.

60. Natural disasters have disproportionate consequences for developing countries, in particular small island developing States and countries with extremely fragile ecosystems. There is a particular need for capacity-building in disaster prevention planning and management and the facilitation of the transfer of early-warning technologies to countries prone to disasters.

61. The substantive orientation of international concerted action in the disaster reduction domain is encompassed in the International Strategy for Disaster Reduction, proposed by the Secretary-General in pursuance of the Economic and Social Council decision on successor arrangements for the International Decade for Natural Disaster Reduction (IDNDR). The Inter-Agency Task Force for Disaster Reduction is an important new institutional arrangement established under the Strategy that introduces a strong call for inter-agency cooperation and coordination to implement the new programme that has succeeded IDNDR.

62. The secretariat of the United Nations Convention to Combat Desertification in those Countries Experiencing Drought and/or Desertification, particularly in Africa in cooperation with international institutions and development cooperation partners, assists affected developing countries in formulating action programmes at the national, subregional and regional levels. At the regional level, country parties have identified the management of water resources as a priority area in the context of the implementation of the Desertification Convention.

63. In Asia and Africa, that theme is considered to be of major concern. The secretariat of the committee has therefore been requested by the countries concerned to facilitate the launching of a consultative process towards the establishment of thematic programme networks in the field of water resources management.

64. In Africa, the consultation process started in September 1998 through the convening of a regional workshop on the promotion of a network on integrated water resources management. As a follow-up to the recommendations of the workshop, a regional thematic programme network for the integrated management of international river, lake and hydrogeological basins was set up and a launching meeting organized in March 2000. The role of the network is to strengthen the capacity of African institutions specialized in the integrated management of water resources with regard to the objectives of the Desertification Convention through information-sharing among member institutions; build partnership agreements to ensure that proposed activities are based on existing programmes; and implementation of the water resource management component of the regional action programme for Africa. The Water Sector Coordination Unit of the Southern African Development Community, based in Maseru, Lesotho, has been selected and designated as institutional focal point for that network.

65. In Asia, priority fields of activities were established in 1997 in Beijing. One of the six thematic programme networks focuses on water resources management for agriculture in arid, semi-arid and sub-humid lands. The overall objectives are to promote cost-effective approaches to the use of scarce water resources; to minimize further soil degradation caused by salinization; and to test methodologies for the reclamation and use of already degraded soils. Seen in a regional context, the network will endeavour to make use of existing expertise in the region, to expand exchange of information within and outside the region, and to facilitate the implementation of joint projects. It is foreseen that a water resources management network will be established by a focal point institution that has extensive experience in the field. A few countries have already expressed their interest to designate one of their relevant institutions to function as focal point for the network.

66. A regional cooperation project on flood control and management in Asia and the Pacific was implemented by ESCAP in 1998/99 to review practices and related experience in the region at the regional, national and river basin levels. The project was implemented in conjunction with the fiftieth anniversary of the establishment of the Bureau of Flood Control (now the Water and Mineral Resources Section) of ESCAP and also as part of ESCAP's inputs

to the preparation for the closing of the International Decade for Natural Disaster Reduction (IDNDR). In the context of this project, a regional workshop was held in October 1998 in Bangkok and a special publication was produced, *Regional Cooperation in the Twenty-first Century on Flood Control and Management in Asia and the Pacific*.

67. ESCAP continued to provide support in the monitoring of annual water-related disasters in the subregion. Within the framework of cooperation between the IDNDR secretariat and ESCAP on mitigation of water-related natural disasters, a regional survey was conducted and a review study was made as part of the preparation for an IDNDR-ESCAP regional meeting for Asia, risk reduction and society in the twenty-first century, which was held in Bangkok in February 1999.

68. ESCAP also continued to assist the Typhoon Committee and the WMO/ESCAP Panel on Tropical Cyclones in their respective annual operations related to the mitigation of water-related natural disasters, including the formulation of a subproject on the mitigation of disasters from debris flow and landslides. ESCAP also provided technical advisory services and inputs to the Typhoon Committee on assessing impacts of El Niño phenomenon in the Typhoon Committee subregion, at a workshop held in Macao, China, in June 1999.

IV. Conclusion

69. Capacity-building in water resources planning and management is a long-term process, which cannot be achieved within a time-bound project. Planning should not be viewed as a rigid "bureaucratic" exercise but rather as a dynamic process, which goes far beyond the top-down approach of central government services and their technical staff to involve users and their representatives. Disappointing results from the implementation of some existing plans have been caused primarily by the lack of ownership of the decision-making process by the most interested parties and by the lack of donor coordination for the implementation of action plans. Thus, water resources planning and management requires time and participation of stakeholders. Nonetheless, operational activities can proceed simultaneously with the planning process, and need not wait for a formal plan to be completed.

70. Governments should continue to play a central role in creating an enabling environment for the complex management of national water resources. Adaptation to a free-market economy and moves towards "privatization", lack of funds and/or previous mismanagement should not justify or encourage a "hands-off" policy. Delegation of too much responsibility to the private sector or to NGOs could lead to supply shortages, high prices or poor quality. Governments ought to continue the promotion of a coherent and integrated policy with regard to water resources. Important governmental responsibilities should remain: in regulating water allocations for different uses of water; in ensuring quality control in the production and distribution of potable water; in liquid waste management and reuse; for dam security, flood protection and prevention; and in ensuring a fair balance with regard to water tariffs, avoiding monopoly situations. The preferable working unit should be defined at the most convenient level of natural units (a hydrologic basin or a group of basins or sub-basins, an extended aquifer system or a conjunction of both, as can best be defined on the basis of current knowledge). Environmental protection should define objectives of water quality for rivers and lakes and protect base flow of streams to protect water-dependent fauna, flora and aquatic ecosystems. Flexibility to adjust to situations from the points of view of water quantity and quality as well as good linkages with other regulations on land use are also recommended. Financing of these services should not be only through more income tax levees or direct payment by users but rather through fees paid by the beneficiaries as a function of the volume of water used and of the pollution loads ejected. Such fees can also be used to assist communities in carrying on necessary investments.

71. Sound planning and management of water resources need to be solidly anchored on reliable information systems. Strict standards for data collection should be established since it has proven more costly to go back on a site and verify dubious information than to collect it properly in a timely way. Data-screening techniques exist, and computer technology can assist in identifying erroneous raw data, but there are situations when this information needs to be collected again when feasible. Any verification work is time-consuming and costly. The current use of geographical positioning systems (GPS) to control or elaborate coordinates of measurement points represents a great step forward. The use of GPS should be

encouraged by teams working in the field, either to generate positioning of new sites or to verify old information. Also, reliable information for water planning and management should include socio-economic data on needs, not as assessed by technicians but as expressed by users, and on current arrangements for allocation among user groups. Basic economic data and information on traditional water uses and water rights are required by the planning process. Socio-economic information may not be adequate and may have to be acquired from other sources, such as the national census, employment statistics, trade and other economic data.

72. At the institutional level, improved coordination and cooperation among the organizations of the United Nations system involved in the field of freshwater resources can greatly increase the effectiveness of system-wide technical cooperation activities, particularly in developing countries. This is clearly illustrated by the ongoing inter-agency initiatives under the aegis of the ACC Subcommittee on Water Resources in the area of arsenic contamination of drinking-water sources and in preparation of the *World Water Development Report*, which will involve close cooperation with national institutions in the areas of information management and capacity-building for data collection and analysis. In addition, the arsenic contamination initiative highlights the importance of rapid system-wide responses by a lead agency or a small group of United Nations organizations when urgent technical cooperation issues are identified.